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AUTHOR Goodstein, Madeline Prager; Sitzman, Barbara Pressey
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ABSTRACT

This document presents activities in the physical sciences. Activities are grouped in the following chapters: (1) "Science and Measurement"; (2) "Measurement Units"; (3) "Introduction to Chemistry"; (4) "The Periodic Table"; (5) "What is Inside an Atom?"; (6) "Bonding"; (7) "Formulas and Equations"; (8) "The Bursting Atom"; (9) "Relationships between Changes"; (10) "Per Problem Solving Made Easy"; (11) "Density, Speed, and Acceleration"; (12) "The Proportional Relationship"; (13) "Force"; (14) "Gravity"; (15) "Work and Machines"; and (16) "Energy and Heat." (JRH)

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RELATIONSHIPS
IN
PHYSICAL SCIENCE

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Madeline Prager Goodstein

with **Barbara Pressey Sitzman**

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In memory of Dr. Lawrence Kershnar

The authors of this book would like to express their appreciation to Dr,. J. William Maben for his help and thoughtful suggestions in making this book possible. MPG, BPS

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GLOSSARY A1 to A3

SAFETY RULES FOR EACH STUDENT

Before starting, make sure that

1. YOU wear safety goggles when using any chemical or heat source or when hammering.
2. YOU know the location and use of the fire extinguisher, fire blanket, and eyewash station.
3. YOU wear shoes at all times.
4. YOU have read the purpose of the experiment and the procedure.
5. YOU never bring food into the laboratory.
6. YOU remove coats, sweaters, and loose jewelry and roll up long sleeves.
7. YOU tie back long hair.

Student Behavior

1. Report to the instructor immediately any personal injury no matter how trivial it may seem.
2. Maintain quiet behavior during laboratory periods.
3. Stay at your laboratory station during experiments except to obtain materials (including chemicals) or equipment.
4. Laboratory desks are not seats. Never sit on them.
5. Do not enter the preparation room without permission from the instructor.
6. Never attempt unauthorized experiments. No laboratory work may be carried on without the instructor's permission.

Student Responsibilities for Equipment

1. Immediately report to the instructor any hazardous conditions of equipment or materials.
2. Treat any test tube that you are heating like a loaded gun. Angle the mouth away from everyone.
3. Turn off water and gas jets when they are not in use.
4. Never put anything hot or wet on the weighing pan of the balance. Protect the balance beam from slamming down.
5. When you break glassware, report it to the instructor. Dispose of broken glassware according to the rules of the instructor.

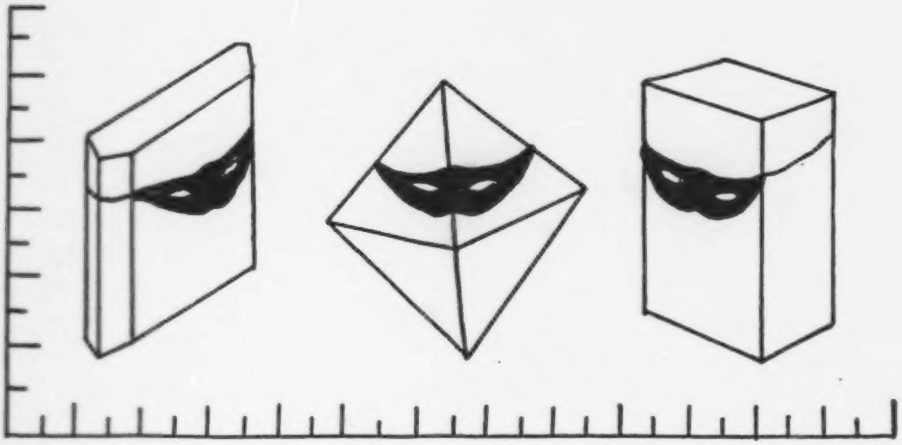
Student Responsibilities for Chemicals

1. After using any chemicals, wash hands before leaving the classroom.
2. Never taste chemicals.
3. Replace caps on bottles or jars immediately after use.
4. Do not take dispensing bottles from the dispensing table.

Student Responsibilities for Cleaning Up

1. Dispose of chemicals to the proper waste containers.
2. Remove all papers and non-chemical solids from the sink and place them in trash can.
3. Flush sink thoroughly.
4. Wash and dry the counter top.
5. Return the safety goggles.

1
SCIENCE AND MEASUREMENT



*Activity 1.1 THE MYSTERY CRYSTAL

Purpose: to make observations on a Mystery Crystal
Materials: a colorless crystal

Safety precautions: Do not handle the crystal with your fingers. Many crystals are poisonous if taken into the mouth. If you hold a crystal in your hand, you may get some of it on your fingers and later might touch your finger to your mouth. Also, never NEVER taste a chemical unless specifically advised by your instructor or by a good authority that it is safe to do so.

Procedure:

1. With a piece of clear plastic to wrap the crystal so that you don't touch it, pick up one of the crystals from the container on the front desk and carry it back to your desk.
2. Observe the crystal carefully. If you want to handle it, use a piece of plastic wrap to hold it so that your fingers don't touch it.
3. Put your name, date, and the title of this activity on a sheet of paper and write as many of your observations as you can on it in ink.
4. Return your Mystery Crystal.

Report Sheet: Your report sheet consists of your list of observations.
At the end of Chapter Two, you will be given another Mystery Crystal. It will be your task to observe it and collect information on it. Then you will return this new crystal to the container of crystals. When everyone has returned a crystal, you will pick your own out of the container and you will show how you identified it. If anyone else claims the crystal, you will have to show evidence to prove that it is yours.

Section 1.1 WHAT IS MATTER?

In order to be able to identify your Mystery Crystal, it will help to learn more about what sorts of things can be observed and measured. We know that our mystery object is made up of matter, but what is matter?

Scientists have several definitions for matter. One definition is:

***MATTER** is something which takes up space and can be pushed or pulled.*

Below, there is a question with two asterisks before it. Such a question is a checkpoint for you. *WHENEVER YOU SEE SUCH A QUESTION,*

THINK ABOUT IT AND TRY TO ANSWER IT.

You will find the answer to each of these questions at the end of the section in which it appears.

Below is a checkpoint.

** Q. 1 Is a ball matter?
** Q. 2 Is a ray of sunshine matter?
** Q. 3 Is water matter?
** Q. 4 Is air matter?

Check your answers to the above with the answers at the end of this section.

Exercise 1.1

1-1 Which of the following is (are) NOT matter?
a. steam; b. color; c. glass; d. moonlight; e. blood;
f. time; g. rain; h. thoughts; i. happiness.

Answer to Q's

Q. 1 Yes
Q. 2 No
Q. 3 Yes
Q. 4 Yes. You can push air with a fan or cardboard and you can feel the air current with your hand, so air must be matter. Another way to show that air is matter is to cool air all the way down until it becomes liquid; liquid air can be pushed or pulled just as any other liquid can.

Section 1.2 WHAT IS PHYSICAL SCIENCE?

Humans have been asking questions about nature since time began. What is fog? What makes an object move? What is rust made of? How far will a ball roll? Scientists study nature and try to answer questions that are based on facts.

The biological sciences study living matter. The physical sciences study non-living matter, what it is, how it behaves, how it changes. Chemistry, physics, geology, astronomy, and biochemistry are all branches of physical science.

This book will examine the two basic physical sciences, chemistry and physics. You will learn important things about our physical universe such as what atoms are made of, what lightning is, how we can see and hear, how a thermometer works, and other basic ideas of science.

Exercise 1.2

1-2 Distinguish between the physical and biological sciences.

Section 1.3 PROPERTIES OF MATTER

Humans have the senses of sight, hearing, taste, feel, and smell. Which senses did you use to describe the Mystery Crystal?

Things that can be described about matter with the aid of the senses are called ***PROPERTIES*** *of matter.*

Science could not have advanced very far if humans had not learned ways to extend their senses with the aid of tools. For example, the microscope and the telescope are tools that help extend the sense of sight. The properties of matter include those where instruments are needed to extend the senses.

Exercise 1.3

1-3 Give an example of matter for each of the following properties.

a. has color
b. is smooth
c. is not smooth
d. can fit into the hand and feels very light
e. can fit into the hand and feels heavy
f. you can't see through it
g. is transparent and liquid
h. has a smell
i. is soft

1-4 List two other properties of matter besides those in 1-3 above.

Section 1.4 MEASUREMENT LABELS AND QUANTITIES

One of the most important processes carried out by scientists is measurement.

MEASUREMENT *finds out how much there is of something.*

By using only the sense of sight without measuring, we can tell that a certain object is longer than a shoe box and shorter than a telephone booth. We can only find out that it is 1.2 meters long by measuring it.

Numbers by themselves are not meaningful for measurements. Each number must have a measurement label. Which would you rather have, 100 dollars or 100 cents? The measurement label make all the difference in your answer.

Every measurement can be stated as a quantity.

A QUANTITY *is a number AND its measurement label.*

Every quantity has two parts: *e.g.*, 6 grams, 1/2 hour, 0.5 minutes, or 2 guitars.

Measurement labels are also called ***MEASUREMENT UNITS*** *or* ***UNITS OF MEASUREMENT***.

All measurements are expressed as quantities.

Exercise 1.4

1-5 Which of the following are NOT quantities?

a. 25 hours
b. 62
c. five hamburgers
d. 1.25 inches
e. 4 dozen
f. long day
g. 32 teeth
h. small houses
i. 3 quarts of milk

(Exercise 1.4 is continued on the next page)

1-6 Is the unit of measurement the same for
- a. one apple and two apples?
- b. one inch and two inches?
- c. one foot and two feet?

Optional: Section 1.5 STANDARD UNITS

Every measurement is based on some kind of standard unit. For example, a standard unit of time is the second.

Unit means one, so a STANDARD UNIT is an accepted measurement for ONE quantity of a particular property.

Other standard units in science include the meter for length, liter for volume, kilowatt for power, and kilogram for mass. Standard units used by consumers include the pound and the yard.

**Q. 1 What is the standard unit for distance travelled in a car in this country?

A standard unit doesn't change. It can be be used by different people in different countries. For example, a duplicate of the standard unit, inch, can be copied onto rulers and used anywhere.

**Q. 2 Is a handspan a good standard unit?

Standard units are essential in a multitude of different situations today. They are important in baking cakes, building skyscrapers, assembling cars, making new chemicals, prescribing medicines, making camera film, buying shoes, and sending a space ship to the moon. Recipes, formulas, clothing patterns, building plans, maps, and airplane routes all depend on standard units.

Whenever a quantity is measured, it is measured either with the aid of a tool that has a standard unit on it or by counting objects one by one. The ruler, weighing scale, clock, electricity meter, car speedometer, and all sorts of other devices use standard units.

Exercise 1.5

1-7 Which of the choices below required the use of a measuring tool?
- a. 60 centimeters long
- b. 5 teachers
- c. big house
- d. 1.35 gallons of milk
- e. 100 kilograms of fuel oil

1-8 For the choices you made in 1-7, list the standard units.

1-9 Which of the quantities in 1-7 were measured by counting?

1-10 Which of the following is a measurement unit for length that can change depending on who is doing the measuring?

a. inch; b. quart; c. thumbwidth; d. kilometer; e. shoelength.

1-11 Why does a measurement tool need a standard unit?

Answers to Q's
Q. 1 the mile
Q. 2 A handspan is not a standard unit because handspans differ from person to person. Note that the foot that we use for measurement is not anybody's foot; it is defined by the U.S. Bureau of Standards as a certain length and it does not change from person to person.

Section 1.6 QUALITATIVE AND QUANTITATIVE, VARIABLES AND CONSTANTS

1.6 A QUALITATIVE AND QUANTITATIVE

What is the major difference between the ideas in Sentence 1 compared to Sentence 2 below?

Sentence 1: John is shorter than Manuel; John is much taller than Eleanor.
Sentence 2: John is one inch shorter than Manuel; John is five inches taller than Eleanor.

Did you say that Sentence 1 tells in what way John differs from Manuel and Eleanor whereas Sentence 2 tells how much the differences are?

Sentence 1 tells "what."
Sentence 2 tells "how much."

Scientists use special terms to describe "what" and "how much" of a property.

QUALITATIVE: *(KWAL-uh-tay-tiv): a description of a property where no measurement is taken.*

Qualitative descriptions have no numbers in them. The following are qualitative: high speed, large space, short distance, young person.

QUANTITATIVE: *(KWAHN-tuh-tay-tiv) a description of a property that requires a measurement.*

Quantitative descriptions tell the quantity of a property--how much there is of it. Quantitative descriptions always have numbers and measurement labels in them as, for example, 65 miles per 1 hour, 0.55 cubic centimeters of space, 2.0 centimeters long, 12 years old.

Exercise 1.6 A

1-12 Which of the following properties is (are) quantitative?

a. salty
b. 36 cm long
c. one second
d. big
e. slow
f. 20 kilograms
g. 24°C
h. 65 years old

1-13 Suppose you are given each of the pairs of substances below. How would you qualitatively tell the difference between them?

a. cranberry juice and apple juice
b. vinegar and water
c. milk and water
d. hot water and cold water

1.6 B VARIABLES AND CONSTANTS

Among other terms that are used frequently in science are *variables* and *constants*.

Variables change. Examples of variables are the height of a student in an eighth grade classroom (the height of each student differs from that of any of the others), the outdoor temperature at any moment, and the total money in a cash register at any moment in the checkout line of a supermarket.

Constants do not change. Examples of constants are the number of inches to a foot and the quantity of money in a locked cash register.

VARIABLES: *properties that can vary (change) under the given conditions*
CONSTANTS: *properties that do not change under the given conditions*

**Q. 1 Is the shape of the Mystery Crystals a variable or a constant?
**Q. 2 Is the identity of the Mystery Crystals a variable or a constant?
**Q. 3 Is the color of the Mystery Crystals a variable or a constant?

Exercise 1.6 B

1-14 Among the following, specify which are variables and which are constants under ordinary conditions.

- a. weather
- b. number of pennies in one dollar
- c. volume of a liter of milk
- d. length of a baby
- e. gasoline in the tank of a moving car
- f. quantity of daylight each day
- g. quantity of pages in this book

Answers to Q's

Q. 1 The shape of the crystals is a variable. Each crystal had a different shape.
Q. 2 The identity of the Mystery Crystals is a constant. It is the same for all the crystals.
Q. 3 The color of the Mystery Crystals is a constant. It is the same for each crystal.

Section 1.7 OBSERVATIONS

Science is based upon observations.

An OBSERVATION is information obtained through the use of the senses.

Seeing is one of the most important senses in science. Observations can also use the senses of smell, taste, touching/feeling, and hearing. In order to be useful to scientists, an observation should be written down, or spoken onto an audiotape, or recorded in some way that other people can use.

The term, DATA , means "set of observations".

Data always state numbers and measurement labels.

Exercise 1.7

1-15 Which of the following are observations?

- a. The clock reads 6 P.M.
- b. You look happy.
- c. You shouldn't do that.
- d. You ought to feel good.

1-16 Which of the choices in 1-15 are (is) measurements?.

---

*Activity 1.2 OBSERVATIONS

Purpose: to compare qualitative and quantitative observations
Materials: 3 jars into which your hand can fit, hot water, cold water, 1 piece of apple, piece of candy, centimeter ruler
Procedure: Below are the instructions for this activity. Your teacher will give you a Report Sheet to use for this activity. In later experiments, you will learn how to write your own report.

Step 1: FEELING THE TEMPERATURE OF WATER

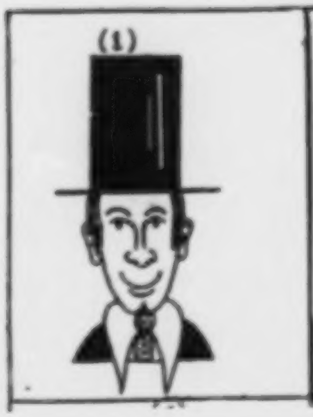
1. Obtain three jars.
2. Fill one with very cold water, one with hot water (not hot enough to burn your fingers), and the third with warm water.
3. Put the fingers of one hand into the cold water for 15 seconds. Then, put them into the warm water. Does the warm water feel cold, warm, or hot?
4. Put the fingers of one hand into the hot water for 15 seconds. Then, put them into the warm water. Does the warm water feel cold, warm or the same as the hot water did?

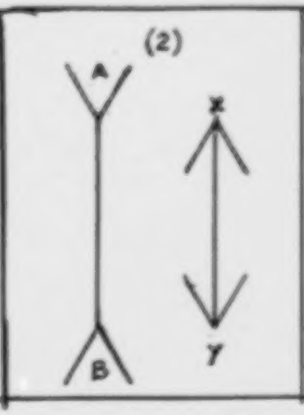
Step 2: FOOLING YOUR TASTE BUDS

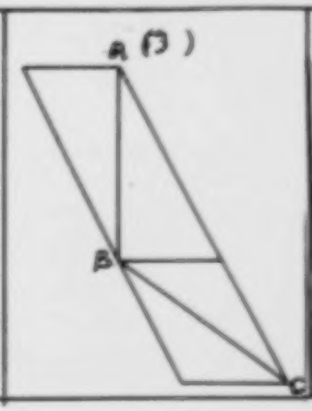
1. Obtain one piece of an apple and a piece of candy.
2. Eat one bite of the apple.
3. Eat the piece of candy.
4. Eat another bite of the apple. Has the taste of the apple changed?

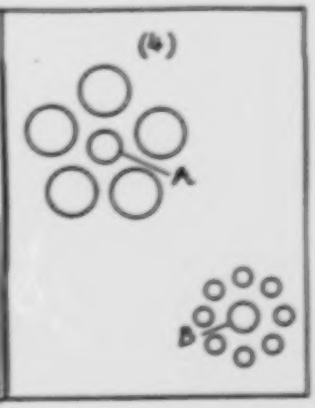
Step 3: FOOLING YOUR EYE

1. Look at drawing (1) below. Decide which is longer, the height of the hat or the width of its brim.
2. With a ruler, measure both lines to decide which line is longer.
3. Examine each of drawings (2) to (4) below. Each can fool your eye. Identify the illusion in each and prove that it is only an illusion.









Questions

Q. 1 Were the observations that you made qualitative or quantitative in
   a. Step 1?
   b. Step 2?
   c. Step 3-1 (without the ruler)?

Q. 2 In Step 3-2, you took a ruler and measured two lengths to compare them. Was this a qualitative or quantitative observation?

Q. 3 What tool could you have used instead of your fingers in Step 1 to find the temperature of the water?

Q. 4 What tool did you use in Step 3 to compare height and width of the hat?

Q. 5 Are the human senses without the aid of tools better at qualitative or quantitative descriptions?

Q. 6 Can the human senses, operating without tools, be fooled? How does the use of tools change this?

Q. 7 Which of the following are quantitative observations? Circle the letters of your choices.
- a. The water is hotter than the soup.
- b. The candy is sweeter than the apple.
- c. The temperature of the olive oil is 36°C. The corn oil is 28°C.
- d. The line is six centimeters long.
- e. This length of foil is 1.3 times as long as that length.
- f. The length is longer than the width

Section 1.8 SCIENTIFIC FACTS AND RELATIONSHIPS

Science is based upon facts.

FACTS are observations that are confirmed by reliable observers.

Ideas that are not built upon facts are not scientific. This is where science differs from other branches of study.

NO FACTS, NO SCIENCE

**Q. 1 Is it a fact that goblins live in the forest? Explain.

It is not scientific to just collect facts. It is not scientific, for example, to just count the number of grains of sand on a beach. Scientists collect facts to try to find some meaningful connections among them.

Meaningful connections between facts are called RELATIONSHIPS.

To find scientific relationships, scientists may try to find out if, perhaps, facts are connected because they involve two variables that always change at the same time. For example, the more sugar that is poured into a bowl, the more the bowl of sugar weighs. The volume of sugar and the weight of the sugar are related.

Astrology is not considered a science because it does not show relationships between the motions of the planets and things that happen to people, even though astrology uses the facts of astronomy.

Exercise 1.8

1-17 *A vehicle is parked in front of 32 Ocean Avenue. The words, "Gotham Ambulance Service" are written on it.*

Read the paragraph above which describes some observations made by a reliable observer and then determine whether each of the statements below is

(1) a fact or

(2) possibly a fact but you can't tell from the observation.

- a. The vehicle has words written on it.
- b. The vehicle is an ambulance.
- c. The vehicle is in front of 32 Ocean Avenue.
- d. Someone at 32 Ocean Avenue is sick.
- e. The number, 32, is written on the building.

1-18 Which of the following statements describe a relationship?
- a. The bigger the beach, the more sand it has.
- b. The sand is one foot deep.
- c. The sand is hot.
- d. The longer the sun shines on the beach, the hotter the sand gets.
- e. All the members of one group of sand grains are yellow.

1-19 Why isn't astrology considered a science?

Answer to Q
Q. 1 If you had actually observed goblins at night or if a reliable observer had seen goblins, it would be considered a fact. Since no such observation seems to have been made, it is not a fact.

Section 1.9 HYPOTHESES

An important process in science is making hypotheses (high-POTH-uh-seez).

*A **HYPOTHESIS** (high-POTH-uh-sis) is a guess, based on insufficient information, about the answer to a question.*

Hypotheses are tentative; the inventor of the hypothesis does not have enough facts to fully believe the hypothesis. More facts are needed. In science, hypotheses are guesses about possible connections between facts.

The scientist can gather facts by observing what is already present in nature or by causing some changes to take place and observing what happens.

> For example, a chemist might hypothesize (high-POTH-uh-size) that the red color in all red leaves is due to a certain chemical which is red and has been found in some leaves. However, the chemist would have to find out (1) if other red leaves always have this chemical, and (2) if the color disappears when the chemical is removed. Until then, the idea would only be a hypothesis. More facts are needed.

A hypothesis can be a prediction based on a connection or an idea about a scientific relationship. It may concern a small event or may concern major ideas of science.

Exercise 1.9

1-20 Which one of the following can best be described as a hypothesis?
- a. The world is round.
- b. There are aliens in outer space.
- c. Matter is made up of atoms.

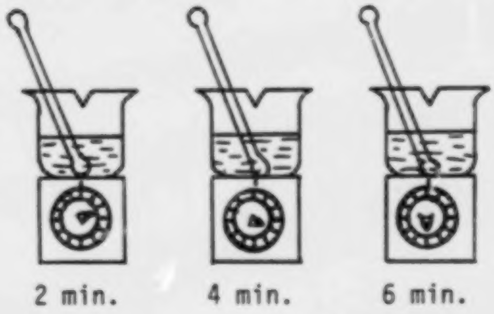
Section 1.10 EXPERIMENTS

1.10 A WHAT IS AN EXPERIMENT?

***EXPERIMENTS** are activities in which changes are made to take place and the results are observed.*

The scientific experimenter causes the change in one variable and then observes any change that results in the other variable.

Suppose, for example, that you want to find the relationship between the time of heating a beaker of cold water and the temperature of the water at the end. You take three small identical beakers and add the same quantity of cold sink water to each. Next, a thermometer is placed in the water in each small beaker. Then each beaker is placed onto an identical electrical burner. One beaker is heated for two minutes, one for four minutes and one for six minutes. You observe the final temperatures and you obtain the following data.

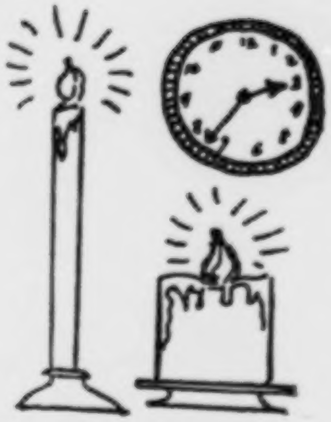

2 min.
4 min.
6 min.

Time of heating	Final temperature
2 min.	30°C
4 min.	45°C
6 min.	60°C

The two variables are the time of heating and the final temperature.

**Q. 1 What is your hypothesis about the two variables?

Optional: 1.10 B CONTROLLED VARIABLES



Michael is trying to find out which burns longer, a fat candle or a thin candle.

**Q. 2 What are the two variables in Michael's experiment?

Michael sets up two birthday candles as pictured at the right.

**Q. 3 What is wrong with Michael's experiment?

When carrying out a scientific experiment to test a hypothesis about the relationship between two variables, only the two variables can be allowed to change. Everything else must be kept the same and not allowed to change, otherwise they will interfere with your experiment.

Variables which are not allowed to change during an experiment are called ***CONTROLLED VARIABLES.***

Controlled variables are kept constant during the experiment. In Michael's experiment, it is important that both candles be the same height in order to compare the effect of the thicknesses. The height of the candles is a controlled variable.

Another variable in Michael's experiment which also must be CONTROLLED is the kind of wax that is used. Both candles must be made of the same wax.

All the variables in a scientific experiment should be controlled except for two. When one of them is allowed to change, the change in the other variable is observed to see if there is a relationship.

The following definitions are useful in describing the variables in an experiment.

INDEPENDENT VARIABLE: *the variable that the scientific experimenter causes to change.*

DEPENDENT VARIABLE: *the variable that changes when the independent one changes.*

CONTROLLED VARIABLES: *variables that the experimenter does not allow to change during an experiment; under the conditions of the experiment, they are constant.*

Exercise 1.10

1-21 Two identical cars, A and B, race down a circular track to the finish to find out which has the better driver.

a. What are the variables?
b. Which is the independent variable?
c. In terms of the variables, what is the hypothesis?
d. Name two variables that are controlled.

Answers to Q's

Q. 1 The longer the time of heating, the higher the final temperature. This experiment shows that a relationship exists between the two variables, time of heating and final temperature.

Q. 2 The two variables are the thickness of the candle (diameter) and the time the candle takes to burn.

Q. 3 The following variables should have been controlled: wax and wick in each candle identical in composition, shape, length, and diameter; same length of wick sticking out of each candle; both candles set upright in the same way and kept out of drafts.

Activity 1.3 TESTING A HYPOTHESIS

Purpose: to see what happens when beakers of different sizes cover a burning candle standing in a little water, and to make a hypothesis based on the observations

Materials: 250 mL beaker, 1000 mL beaker, two birthday candles, a foil pie plate, small lump oil-based clay (non-hardening clay), matches

Hypothesis: What difference do you expect to see between burning the candle in a small air space and in a larger one?

Procedure: Write down all your observations.

Step 1: BURNING A CANDLE INSIDE THE SMALLER CONTAINER

1. Obtain the 250 mL beaker, one birthday candle, the pie plate and clay, and matches.
2. Press the clay in a lump onto the middle of the pie plate.
3. Set the candle into the clay so that it is firmly upright.
4. Add water to the pie plate to about 1½ cm high.
5. Light the candle.
6. Immediately, turn the 250 mL beaker upside-down and place it into the pie plate over the candle. The rim of the beaker should be entirely under the water.
7. Observe.
8. Remove the beaker. Rinse it out and return it. Take the 1000 mL beaker, and another candle.

Step 2: BURNING A CANDLE INSIDE THE BIGGER CONTAINER

Repeat 3 to 7 in Step 1 with another birthday candle and the 1000 mL beaker.

Conclusion: Based on your observations,

a. write a hypothesis to explain why the candle went out.
b. write a hypothesis to explain the difference between what happened in the smaller container and the bigger one.

Report: Write a report on this experiment. At the end, answer the following questions.

Q. 1 Was this experiment qualitative or quantitative?

Q. 2 In Step 2, what was the dependent variable?

Q. 3 In Step 2, what was the other variable that changed?

Section 1.11 THEORIES

When enough facts have been gathered to really believe a hypothesis, the hypothesis is graduated to become a theory.

A ***THEORY*** *is an explanation which connects the facts.*

For example, it is a theory that matter falls to earth because the earth's mass attracts the mass of the object.

Theories can never be proven. No theory is final. It is always possible that some newly discovered fact will contradict it (disagree with it). The theory must agree with all the facts.

When Dalton first theorized the concept of atoms, he believed atoms to be little hard spheres which could not be subdivided. This part of Dalton's theory has been discarded because we now know that atoms can be shattered into different pieces.

Exercise 1.11

1-22 Select the choice that best fits each statement below from among the following:
(A) fact; (B) hypothesis; (C) theory.
- a. Objects fall to Earth due to the effect of gravity.
- b. Many plants are grown from seeds.
- c. The movement of the stars affect our daily lives.

CHAPTER ONE REVIEW

Note: Items marked with an asterisk, *, are from Optional Sections.

Vocabulary

Matter
Quantity
Constant
Standard unit
Color
Qualitative
Data
Physical Science
Unit of measurement
Quantitative
Measurement

Place one of the vocabulary terms above in each blank below. Each of the vocabulary words may be used only once.

1. Another name for measurement label is ______________________.
2. ________________________ is a property of matter.
3. ________________________ can be pushed.
4. ________________________ are records of scientific observations.
5. A(n) ________________________ is a number and its measurement label.
6. A(n) ________________________ measurement tells how much there is of a property.

*7. An example of a(n)________________________ is the kilometer.

8. A(n) ________________________ gives the quantity of a property.
9. A(n) ________________________ doesn't change.
10. An observation without a measurement is ________________________.
11. ________________________ is the scientific study of the behavior of non-living matter.

Facts
Controlled
Hypotheses
Relationships
Experiments
Variables
Theories

Place one of the words or phrases above in each blank below. Each may be used only once.

12. Observations that are confirmed by reliable observers are called ____________________________.

13. ____________________________ are properties which can change under the given conditions.

14. ____________________________ are guesses about possible connections between facts.

15. ____________________________ are guesses that connect facts to each other.

16. Another word for **connections** between facts is ____________________________.

17. ____________________________ are explanations of relationships which are well supported by observations.

*18. ____________________________ variables are not allowed to change during the experiment.

Applications

Mark each of statements 1 to 11 below as true or false.

T F 1. Sunshine is matter.
T F *2. A measurement that uses a standard unit is quantitative.
T F 3. Given two oranges, "oranges" is a measurement unit used in counting.
T F 4. A weighing scale is a measurement tool.
T F 5. The length of the leaves on an oak tree is a variable property.
T F 6. It is a fact that the rockets to the moon causes changes in our weather.
T F 7. Observing the stars through a telescope is an experiment.
T F *8. Experimenters try to control all but two variables in an experiment.
T F 9. Glass is matter.
T F 10. Sound is matter.
T F 11. Biology is not a science.

Answer each of the following.

*12. Which of the following is (are) not a good standard unit?
a. footspan; b. second; c. quart; d. meter

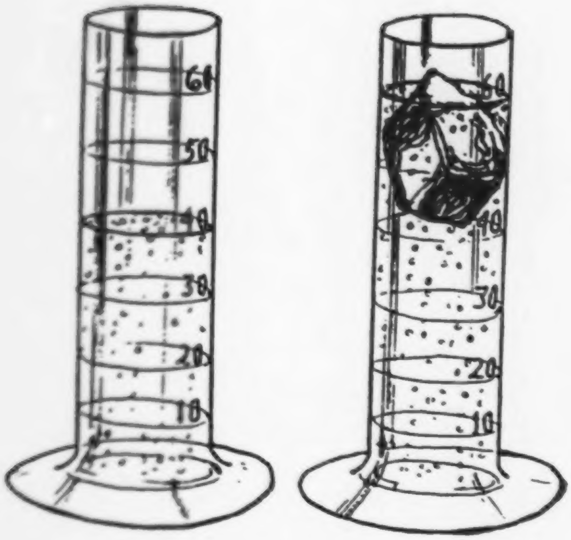
*13. The time that it takes to heat up different quantities of water to the same temperature is measured in several experiments.
a. What are the variables that are measured?
b. Which is the independent variable?
c. What variable is controlled?

14. Why is it not considered scientific to just collect facts?

15. For each of the following, state whether it is a fact, hypothesis, or theory.
    a. An object on a shelf fell down when the shelf was removed.
    b. According to Newton, objects are attracted to each other due to the force of gravity.
    c. Although nobody saw it, the evidence shows that the clown committed the crime.
    d. The planet Pluto is made of green cheese.
    e. The newspaper reported that the stock rose 5 points on August 11.
    f. Until better evidence comes along, it looks as if the butler committed the murder.

16. Records of quantitative observations are called (select the best choice):
    a. note-taking; b. observations; c. data; d. variables.

17. Which is (are) a variable?
    a. the number of stars on our flag
    b. the number of seconds in one minute
    c. the height of this school
    d. the quantity of moonlight each night



2

MEASUREMENT UNITS

Section 2.1 THE FUNDAMENTAL DIMENSIONS

When you read the temperature on a glass thermometer, what is it that is actually being measured?

What is being measured is a length, the length of the silvery or red liquid column.

When the speed of a supercar racing along the salt flats of Bonneville, Utah, is measured, what is it that is actually measured? It is length and time--the length of the flats covered and the time that it takes.

In fact, almost everything in nature can be measured in terms of three variables: length, mass, and time.

This doesn't mean that these are the only three variables around. Scientists take measurements of many variables besides length, mass, and time. What it does mean is that properties can be measured using measurements of length, mass, and/or time.

Length, mass, and time are called the fundamental dimensions (dih-MEN-shuns) of nature.

Scientists have adopted standard units for length, mass, and time which they all use. Their **base units** are: the meter for length; the kilogram for mass; the second for time. You may be familiar with these from the metric system.

The entire system of units that scientists use is called the Système Internationale (sis-TEMM in-tuh-NASH-ee-uh-NAL), abbreviated as SI. It has many metric units in it.*

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*There are seven base units in the SI. In addition to the meter, kilogram and second, they include units for temperature, light intensity, amount of substance, and electric current.

Exercise 2.1

2-1 Which ones of the following measure fundamental dimensions? (Note: the unit does not have to a base unit nor even be an SI unit.)

a. seconds
b. kilograms
c. pounds
d. miles
e. square feet
f. quarts
g. acres
h. shoelengths
i. hours
j. kilowatts

2-2 Which of the choices in 2-1 are base SI units for the fundamental dimensions?

Section 2.2 LENGTH

The SI unit for length, a fundamental dimension, is the meter. You can use a meter stick to find the length of a meter quantitatively. A meter is about the distance from the floor to a doorknob or the length of a baseball bat. The abbreviation for meter is **m**.

**Q. 1 Is your height closer to 1 m or to 10 m?

For short distances such as the width of a thumbnail or a pencil, the meter is too long to use without getting into inconvenient decimals and fractions. On the other hand, a meter seems too short to use when giving long distances such as that between Miami and Seattle. The SI and metric system both use prefixes (PREE-fix-uhz) to adjust the size of a base unit. Below is a table of the scientific prefixes which are used in this book.

Prefix	Pronunciation	Abbreviation	Meaning
kilo-	KILL-uh	k	one thousand (1000)
deci-	DESS-uh	d	one tenth (1/10)
centi-	SEN-tuh	c	one hundreth (1/100)
milli-	MILL-uh	m	one thousandth (1/1000)

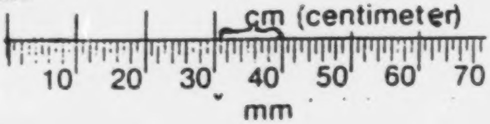
A decimeter (dm) is one tenth of a meter, 0.1 m.
A centimeter (cm) is one hundredth of a meter, 0.01 m.
A kilometer (kill-OMM-uh-tuh, abbreviated km) is 1000 meters long.

You should learn the meaning of the above prefixes by heart.

**Q. 2 What is a millimeter? What is its abbreviation?

**Q. 3 How many millimeters are there to a meter?

Notice that SI abbreviations do not have periods.



Exercise 2.2

2-3 Arrange in the order of size starting with the smallest: centimeter, kilometer, meter, millimeter.

2-4 How many meters laid end to end make up one kilometer?

2-5 If you bank one kilodollar, how many dollars are deposited?

2-6 a. What is a centidollar? What is the common name for it?
b. What is a decidollar? What is the common name for a decidollar?

2-7 Is the width of a refrigerator closest to 1 m, 1 cm or 1 km?

(Exercise 2.2 is continued on the next page)

2-8 Identify the following from its abbreviation:
a. dm; b. km; c. cm; d. mm

2-9 Which one in each of the following pairs is correct?
a. 0.1 m = 1 dm or 1 m = 0.1 dm
b. 1/100 cm = 1 m or 1 cm = 1/100 m
c. 1 km = 1000 m or 1 m = 1000 km
d. 0.001 mm = 1 m or 1 mm = 0.001 m

Answer to Q's
Q. 1 Your height is closer to a meter.
Q. 2 A millimeter is one thousandth of a meter, 1 mm = 0.001 m.
Q. 3 There are 1000 mm to 1 m.

Activity 2 . 1 MEASURING LENGTH

Purpose: to gain experience in the size of a meter and centimeter.
Materials: meter stick
Procedure: Make records of all your observations.

Step 1: THE METER

1. Obtain a meter stick and use it as if it were unmarked to make rough measurements for the following to within about one-quarter of a meter.
2. Measure the height of the room.
3. Measure your height.
4. Measure the distance from the floor to the doorknob.

Step 2: THE CENTIMETER

1. The meter stick is divided into short lengths by lines that run the width of the stick. Find the markings that divide the meter into 100 shorter lengths or subdivisions. Each of these is one centimeter.
2. On your Report Sheet, draw and label the length of one centimeter.
3. How many centimeters are there on the meter stick?
4. Measure each of the following to about the nearest half-centimeter.
   a. your thumbnail width
   b. your handspan: spread your fingers out as far as you can and measure straight across from outside the thumb to outside the little finger
   c. the height from the floor to the doorknob on the classroom door
   d. your height

Of course, you have been writing each of the quantities that you measured as a number with its measurement label.

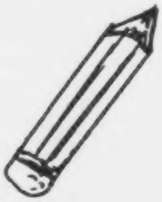
Report Sheet

Your report sheet should include the purpose, your observations, and answers to the following questions.

Questions

Q. 1 Often, when a measurement is repeated, it does not exactly agree with the previous measurement. What could cause such differences, over which you have no control, when a ruler is used?

Q. 2 Which of the following is (are) very unlikely?
a. The automobile is five meters long.
b. The ceiling is one meter high.
c. Your hand is fifty centimeters long.
d. The pencil is 8 centimeters long.
e. The pond is ten meters wide.
f. The bathtub is two meters deep.



Q. 3 Most of the students in this class are between (select best choice)
- a. zero to 1 meter tall
- b. 1 meter to 2 meters tall
- c. 2 meters to 3 meters tall

Activity 2.2 MEASURING LENGTH IN MILLIMETERS

Purpose: to gain experience in the size of a millimeter
Materials: centimeter ruler
Procedure: Make records of all your observations.

Step 1: THE MILLIMETER

1. Obtain a centimeter ruler. Each centimeter is divided on your ruler into smaller lengths. Each of the smaller divisions of a centimeter is called a millimeter. Examine your ruler to answer the following questions.
2. How many millimeters are there in each centimeter?
3. Each millimeter is what fraction of a centimeter?

Step 2: MEASUREMENTS

Measure the number of millimeters, to the nearest whole millimeter, of
1. the thickness of your thumbnail
2. the length of your pinkie finger
3. the thickness of your pencil

Report: Your report should include the purpose, observations, and answers to the following questions.

Q. 1 Which of the following is (are) very unlikely?
- a. A dollar bill is about 1/4 millimeter thick.
- b. Her handspan is 1 mm.
- c. Your nose is about 25 mm wide.
- d. A dime is about 1 mm thick.

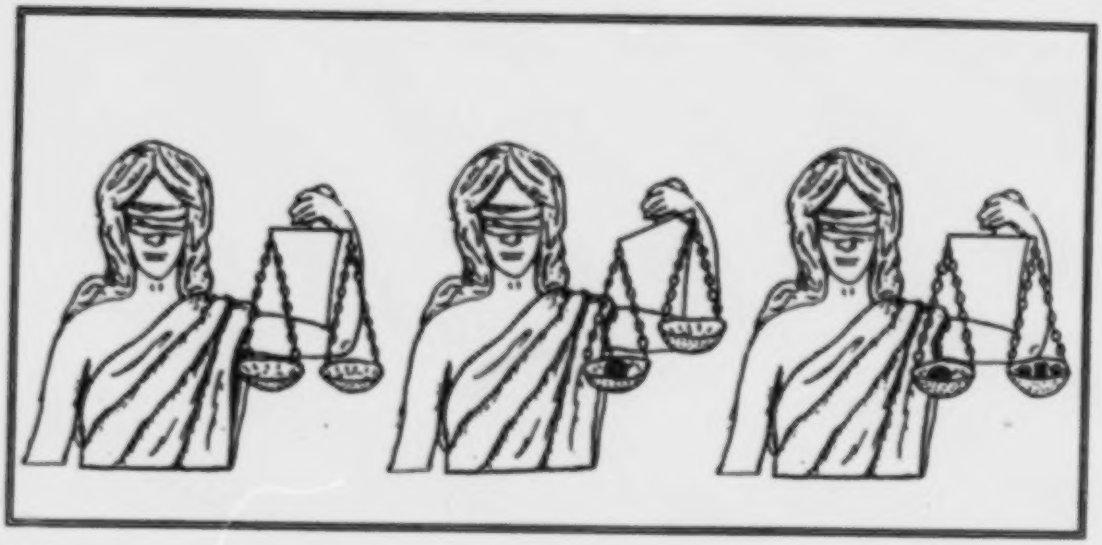
Q. 2 How many millimeters are there to one meter?

Section 2.3 MASS

MASS is a measure of the quantity of matter in an object; it is a fundamental dimension. Mass has two very important properties:
(1) inertial (in-ERR-shall) property: mass can be pushed or pulled.
(2) gravitational property: mass is affected by a gravitational field.
Both of these properties will be discussed further in later chapters.

On the earth, the gravitational property gives weight to a mass. The more mass an object has, the more it weighs on earth.

Mass can be measured on the earth by a beam balance. In courthouses, you can sometimes see a drawing or carving of a beam balance showing that justice is balancing deeds. The diagram below illustrates how a beam balance works. The two pans hang from a stick (beam) balanced on an edge of a triangular bar under it. The unknown mass in one pan is balanced by pieces of metal of known mass in the other pan so that both pans are again level with each other. The total mass of the metal pieces equals the mass of the unknown.



On the moon, the same object weighs much less but it still has the same mass. In outer space, the object has no weight at all but its mass remains the same. The mass of an object never changes as long as no portion of it is removed. Neither change in location nor increase or decrease in temperature or in pressure affects mass as long as none of it is removed.

The kilogram (abbreviated kg) is the SI base unit of mass. Five large apples or a quart of milk have a mass of about 1 kg. Note that although a gram is an SI unit, it is not the base unit for mass.

A gram (g) is one thousandth of a kilogram; there are 1000 g to a kilogram. A paper clip has a mass of about 1 g.

A decigram (dg) is one tenth of a gram; there are 10 dg to a gram.

**Q. 1 What is a milligram (mg)?

**Q. 2 Skelly wrote on his paper, "My science book has a mass of 3 g." Mark Skelly's statement as right or wrong. Explain.

Exercise 2.3

2-10 Which of the following is (are) very unlikely?

a. The school principal has a mass of 1 kg.
b. A pencil has a mass of about 1 kg.
c. Four large oranges have a mass of about 1 kg.
d. The diamond in a ring has a mass of about 1 g.
e. A glass of water has a mass of about 1 g.
f. A tablespoon of water has a mass of about 1 mg.

Answer to Q's

Q. 1 A milligram is one thousandth of a gram; 1 mg = 0.001 g.

Q. 2 Since 3 grams is about the mass of three paper clips, it is very unlikely that a science book has a mass of only three grams. Mark it wrong.

Activity 2.3 MEASURING MASS

Purpose: to use the laboratory balance .

Discussion: You will use a laboratory balance to measure mass. There are several types of balances. Your teacher will show you how to use the balance that is in your classroom.

The laboratory balance measures mass in grams.

Materials: laboratory balance, 2 objects to be massed

Procedure: (Note: In the following, make sure that you identify the object that is observed.)

Step 1: FINDING MASS

1. Obtain two objects to be massed.
2. Use the laboratory balance to find their masses. Remember to record each mass as a quantity, not as a number.

Step 2: COMPARING MEASUREMENTS

1. Exchange your two objects with another team in the class. Do not let them see your data.
2. Find and record the masses of the new objects.
3. Give the other team your data for Steps 1 and obtain theirs.
4. Compare your data with that of the other team.

Report Sheet:

Write your purpose, observations, and answers to the following questions.

Questions:

Q. 1 List as many causes as you can to explain why the two sets of data in Step 2 may differ.

Q. 2 Which of the following choices are most likely to have a mass less than 10 grams?

a. a large paper clip
b. your science textbook
c. a glass of water
d. a sheet of notebook paper
e. your fingernail
f. a large apple
g. a penny

Q. 3 All measurements made with a measuring tool such as a ruler or a balance are inexact. List reasons why you think this is so.

Section 2.4 TIME

The SI unit for time, a fundamental dimension, is the second, abbreviated as s. The same prefixes that are used for length and mass are also used for the second.

In addition to the second with its SI prefixes, scientists also use the minute and hour as measurement units for time even though they are not prefixed SI units. Note that the abbreviations, **min.** and **hr.**, end with a period unlike SI units.

For many years, clocks were operated by mechanical devices that depended on springs or pendulums to work. By these means, accurate clocks were produced some of which were often marvellous works of art. Within the last decades electric clocks and battery-driven digital clocks and watches have come into general use. The most precise clock today is the atomic clock which can measure to billionths of a second.

Exercise 2.4

2-11 Which is longer, a centihour or a minute? Explain.

Section 2.5 VOLUME

***VOLUME** is the space occupied or enclosed by something.*

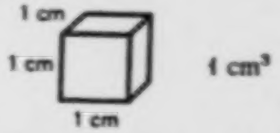
When you blow into a balloon, the space it takes up becomes bigger and bigger; the volume of the balloon is increasing. A refrigerator takes up much more space than a shoe box; the refrigerator has a larger volume than the shoe box. Some objects are square, some round, some blobs, some irregular but, no matter what the shape, their volume is the space that they occupy or enclose.

Some objects have regular shapes; their volumes can easily be measured with a ruler. The volume of a box measured as one meter long, one meter wide, and one meter high is

$1\ m \times 1\ m \times 1\ m = 1\ m^3$ (read as one cubic meter)

A cubic meter is about the space enclosed by a standing card table from top to floor or by a kitchen refrigerator.

In the physical science laboratory, scientists rarely measure objects the size of a refrigerator. A smaller unit for volume is the cubic centimeter, cm^3 A cm^3 is the space occupied by a box with sides each one centimeter long.



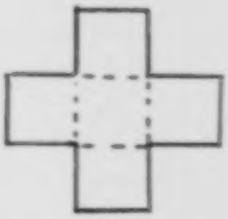
Although it is not an SI unit, scientists also use a metric unit called the liter (abbreviated as L or l). The plastic bottles for flavored soft drinks in supermarkets come in one or two liter sizes.

The milliliter (1/1000 of a liter) has been defined so that it equals 1 cm^3. Hence,

$$\boxed{1\ L = 1000\ mL = 1000\ cm^3}$$

Activity 2.4 CUBIC CENTIMETER

Purpose: to make a cube with a volume of one cubic centimeter
Materials: sheet unlined paper, scissors, paper clips, tape, ruler
Procedure:
Draw the diagram at the right on a sheet of paper making each line one centimeter in length. Cut on the continuous lines. Then, fold on the dashed lines and tape together to make a cube one cubic centimeter in volume.



Report Sheet:: Hand in the answers to the questions below.
Questions:
Q. 1 Name three objects with a volume of approximately 1 cm^3.
Q. 2 For the cube you made, what is the
  a. length of each side of the cube?
  b. area of each side of the cube?
Q. 3 a. Suppose you lined up ten cubes in a row. What is the volume of the row?
  b. What is the total volume of 2 rows of 5 cubes each?

Exercise 2.5

2-12 Which of the following measure volume?
- a. the distance from your desk to the teacher's desk
- b. how much your hand can hold
- c. your footspan
- d. the number of pills in a bottle
- e. the area of a football field
- f. a cupful
- g. a tablespoon of salt
- h. length x width of a square
- i. length x width x height of a rectangular container

2-13 A block is 2 meters long, one meter deep, and one meter high. What is its volume?

2-14 Which of the following have volumes closer to a cubic centimeter than to a cubic meter?
- a. slice of watermelon
- b. bass fiddle
- c. M&M® candy
- d. automobile
- e. desk
- f. pencil eraser

2-15 Which is bigger?
- a. 1 m^3 or 1 L
- b. 1 mL or 1 L
- c. 1 m^3 or 1 mL
- d. 1 cm^3 or 1 mL

2-16 For each blank, fill in the number needed to make an equality.
- a. 1 L = cm^3
- b. 1 L = mL
- c. 1 mL = cm^3
- d. 1 cm^3 = mL

2-17 How many cubes 1 cm^3 in volume are needed to make a layer which completely covers the bottom of a box 2 cm x 2 cm x 2 cm?

Activity 2.5 FINDING VOLUME BY THE WATER DISPLACEMENT METHOD

Purpose: to find the volume of one paper clip by the method of displacement of a liquid

Discussion: While it is simple to find the volume of a regular object such as a box or sphere by taking measurements of length, the volume of an object of irregular shape is not so easily measured.

One way to find the volume of an irregular solid object is to use the method of water displacement. For example, suppose you wanted to find the volume of a small pile of sand. You put a measured volume of water into a container. Then add the sand. The water is displaced up and away from the sand. The increase in volume is due to the volume of the sand, so the difference in the volume of the water before and after is the volume of the sand.

Materials: 100 mL graduated cylinder, water, 10 to 30 No. 1 paper clips.

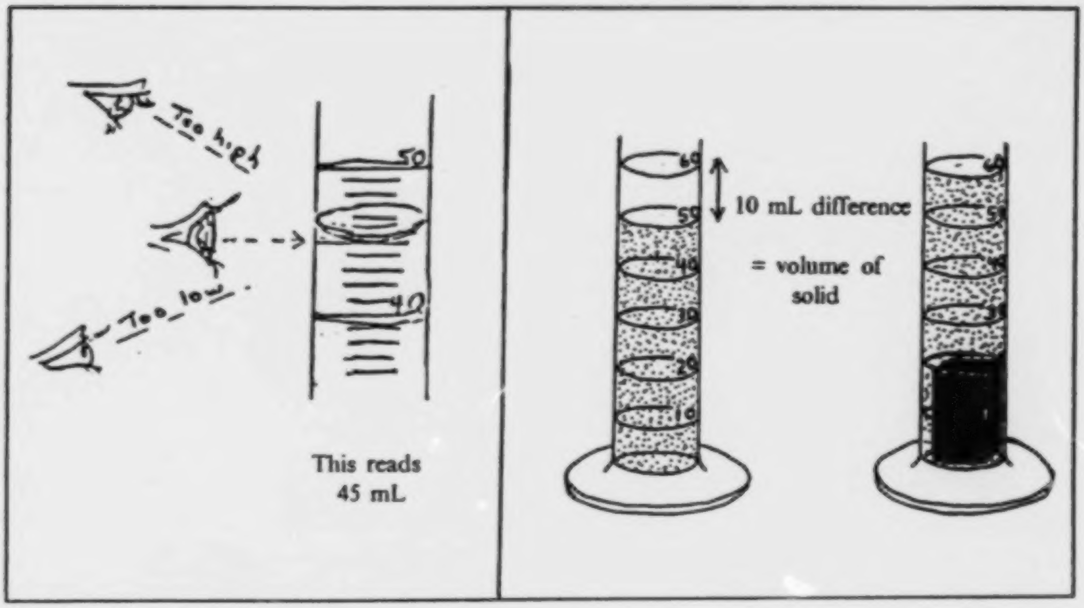
Procedure:

Step 1: THE GRADUATED CYLINDER

1. Obtain a 100 mL graduated cylinder.
2. Study the 100 mL cylinder to find out how to use it. Here are some questions to help you. You do not have to answer these in your report.
   - a. Is the zero marking at the top or bottom of the cylinder?
   - b. How many milliliters does it hold?
   - c. How can you tell when you have 20 mL of water in the cylinder?
   - d. Where is the marking for 70 mL?
3. How many spaces are marked off between 20 mL and 30 mL?
4. How much is each one of the smaller divisions worth?
5. How closely can you read a volume in milliliters– to integers, to one decimal place, to two decimal places?

Step 2: THE MENISCUS (men-ISS-kuhss)
When water is placed into glass, the surface of the water curves down from the glass.

The surface layer of a liquid is called its ***MENISCUS***.



Read the volume of water at the lowest point on the meniscus. Keep your eye level with the meniscus when you read it.

1. Pour 40 to 45 mL of water into the cylinder.
2. Read the volume of water. Exchange your cylinder with someone else and take readings. Check that your readings agree.

Step 3: THE VOLUME OF A PAPER CLIP

Your task is to find the volume of one paper clip. If you use just one paper clip with the water displacement method, it makes such a small change in the volume of the water that you really can't feel sure of your result. Instead, it is suggested that you drop in ten, twenty, or even thirty paper clips and find the volume for all of them by the water displacement method. Knowing the volume of all the paper clips, and knowing how many paper clips you have, you can figure out the volume of one paper clip. Be sure to write down all your data, that is,

(1) the height of the water before you add the clips,
(2) the number of paper clips that you add,
(3) the height of the water afterwards, and
(4) the volume of all the paper clips: (3) minus (1).

Report Sheet: In your report, write your purpose and observations. Give your procedure for finding the volume of one paper clip. Calculate the volume of one paper clip and show your calculations.

Optional: Section 2.6 CAN VOLUME CHANGE?

We have learned that the mass of an object does not change no matter where it is. It also doesn't matter what temperature the mass has nor even what shape it has. Is the same thing true for volume? Does the volume of an object change when its shape changes? Does it change when the temperature changes?

The answer is that volume is not like mass because it can change under certain conditions. Changing the temperature of matter by heating and cooling can cause it to change in volume. For example, warming a sealed balloon causes the air in it to expand (become bigger). Pressing on matter may cause it to change volume.

What if only the shape of an object changes? Does its volume change, too?

You will find out for yourself whether the volume of a solid changes with shape by carrying out an experiment.

Activity 2.6 DOES THE VOLUME OCCUPIED BY A SOLID CHANGE WHEN ONLY ITS SHAPE CHANGES?

Purpose: Your task in this activity is to find out whether the volume of a solid changes when only its shape is changed. For example, if you have a lump of clay and shape it into a rope, a pancake, a sphere, and a cube, does its volume change each time?

Hypothesis: Write your hypothesis.

Materials: Chunk of oil-based clay, water displacement cup (your teacher will demonstrate how this works) or a substitute for the displacement cup, 100 mL graduated cylinder, water.

Procedure: Press the clay and measure the volume. Do this for at least four different shapes.

Conclusion: Based on your data, form a conclusion about whether the volume changes when only the shape changes.

Report Sheet: Write a report of your experiment including the purpose, hypothesis, your procedure, and conclusion. Also, answer the following questions.

Q. 1 What are the two variables in this experiment?

Q. 2 What is the independent variable in this experiment?

Q. 3 What other variables that might possibly change were kept under control in this experiment?

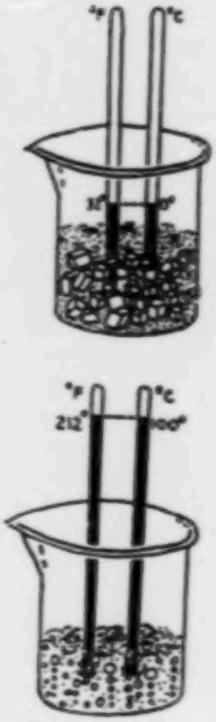
The same rule of nature that applies to the volume of a solid when its shape changes also applies to a liquid. Gases, however, do not have a definite shape so the rule does not apply to them at all.

Exercise 2.6

2-18 For which of the following is there a change in volume for the underlined matter?
- (a) water which is poured from a tall cylinder into a bowl
- (b) dimes in a stack after rearranging into two stacks
- (c) pavement when the sun heats it up
- (d) a bar of margarine which is squashed into a long roll
- (e) hot oil which is cooled down
- (f) a lump of clay from which a piece is removed
- (g) a cube of metal which is placed into water at the same temperature

2-19 For which of choices (a) through (g) above does the mass of the underlined matter change?

Optional: Section 2.7 TEMPERATURE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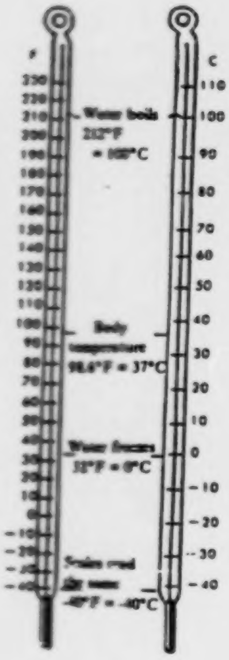
100°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-30
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50
40
30
20
10
0
-10
-20
-30
-40
Water boils 212°F = 100°C
Body temperature 98.6°F = 37°C
Water freezes 32°F = 0°C
Scales read the same -40°F = -40°C

TEMPERATURE tells us how hot or cold something is. How is it measured?

Temperature can be qualitatively measured by the skin on our bodies. It can be quantitatively measured by the change in length of a column of liquid on warming or cooling.

Scientists generally use the Celsius temperature scale for everyday laboratory work.*

The name for one measurement unit of temperature on the Celsius scale is
CELSIUS DEGREE.

To mark degrees on a Celsius thermometer, the boiling point and freezing points of pure water are used.

Picture a blank thermometer to be marked with the Celsius scale. The bulb end is placed into a bowl of water and ice. The water and ice are stirred around to be sure that the water is as cold as the ice. A little line is marked on the thermometer at the top edge of its column of liquid. The line is labeled 0°. The illustration shows how a thermometer is calibrated in Celsius degrees. For those of you familiar with the Fahrenheit scale, the illustration includes one for comparison.

Next, the thermometer is removed and the water is heated to boiling. The Celsius thermometer is placed into the boiling water. When the column of liquid in the thermometer stops rising, another thin line is marked at its top edge and labeled 100°.

The length between the two markings is divided by short lines into 100 spaces. Each space counts for one Celsius degree.

Examine the illustration of the thermometer above. Notice that body temperature is 37°C and room temperature is about 20-22°C.

Exercise 2.7

2-20 a. If a person has a temperature of 40°C, is that person very sick, well, or dead?
b. If it is 10°C outside, is it warm, cold, or freezing?
c. If water is at a temperature of 50°C, will it feel comfortably warm?

2-21 Suppose you are marking the degrees on a Celsius thermometer with only 100°C and 0°C on it. Where would the 25°C mark go? Where would the 50°C mark go?

---

*The SI has a special unit for temperature called the kelvin. The temperature in kelvins equals the Celsius temperature plus 273.

Optional: Section 2.8 HOW TO REMEMBER CONVERSION EQUATIONS FOR SI-METRIC UNITS

Suppose you want to convert a measurement in kilometers to the same length in meters. You know that "thousand" is involved. Which will you use?

1000 km = 1 m?
or 1000 m = 1 km? Only one can be right!

Start with a mental picture of the units. A kilometer is much much longer than a meter. 1000 km will be even longer than a meter so 1000 km ≠ 1 m. It has to be that 1000 m = 1 km.

Another way to recognize which is the correct equation is to recall that kilo means 1000. When it precedes a unit, it means 1000 of that unit. One kilometer means one thousand meters, so 1 km = 1000 m.

With prefixes which stand for fractions, such as *centi* for 1/100, it may be a little harder to set up the equality. Suppose you want to convert a measurement in centimeters to the same length in meters. You know that "hundred" is involved. Which is correct,

1 m = 100 cm?
or 1 cm = 100 m?

You know that *centi* means *one hundredth*. Hence, one centimeter is one hundredth meter (or one hundredth of a meter). A centimeter must be much smaller than a meter so it cannot equal 100 m. It has to be that 100 cm = 1 m.

If this doesn't work for you, here's another suggestion. Think of cents and dollars. A cent is a centidollar; it is 1/100 of a dollar. 100 cents = 1 dollar. Likewise, 100 cm = 1 m or 100 cg = 1 g and so on.

A dime is a decidollar; it is 1/10 of a dollar. 10 dimes = 1 dollar and, likewise, 10 deciliters = 1 liter, 10 dm = 1 m, and 10 dg = 1 g. Treat *milli* units like *deci* units and *centi* units.

Use whichever system works best for you.

Exercise 2.8

2-22 Fill in the blanks.

a. 1 g = ____________________ mg
b. 1 m = ____________________ cm
c. 1 km = ____________________ m
d. 1 L = ____________________ mL
e. 1 s = ____________________ ds

2-23 Which is the true equation?

a. 1000 kg = 1 g?
   1000 g = 1 kg?
b. 1 cm = 100 m?
   1 m = 100 cm?
c. 1 m = 1000 mm?
   1 mm = 1000 m?
d. 1 ds = 10 s?
   1 s = 10 ds?

2-24 a. 1000 m = 1 ____________________
b. 100 cm = 1 ____________________
c. 10 dg = 1 ____________________
d. 1000 g = 1 ____________________

Activity 2. 7 YOUR MYSTERY CRYSTAL

It is, at last, time to complete the Mystery Crystal activity. The chemical formula of your Mystery Crystal is $C_{12}H_{22}O_{11}$.

After you have finished obtaining as much data as you can about it, return your crystal to the container of crystals. When everyone has returned a crystal, you will pick your own out of the container. If anyone else claims the crystal, you will have to show evidence before a panel to prove that it is yours.

Write a report in which you tell how to identify your crystal.

Chapter Two Review

Vocabulary

Mass
Temperature
Milli-
Degree
Liquid displacement
Cubic centimeter
Kilo-
Length
Meter
Cubic meter
Second
Deci-

Select a vocabulary word from the above list to fill in the blanks below. Each vocabulary word may be used only once.

1. __________________________ means one thousand.
2. A __________________________ has the same quantity of volume as a box with square sides each 1 cm x 1 cm.
3. A __________________________ is the measurement unit for temperature.
4. __________________________ means one-tenth.
5. __________________________ means one-thousandth.
•6. __________________________ tells us how warm or cold something is.
7. A __________________________ has the same volume as a box with square sides each 1 m x 1 m.
8. __________________________ takes place when a solid is placed into a liquid in which it is insoluble.
9. A(n) __________________________ is the scientific unit of length.
10. __________________________ is the quantity of matter measured on a balance.
11. The __________________________ is the scientific unit of time.
12. __________________________ is the distance between two points.

Applications

Questions 1-18 are true or false questions.

T F *1. As the shape of an object is made thinner, it occupies less volume.
T F 2. A liter has the same volume as one thousand cubic centimeters.
T F 3. A paper clip has a mass of about 10 g.
T F 4. A kilosecond is shorter than an hour.
T F *5. The volume of water does not change when its temperature changes.
T F 6. 1000 m = 1 km
T F 7. 100 m = 1 cm
T F 8. 1 L = 1000 mL
T F 9. 1 g = 1000 mg
T F 10. 1 dm = 10 m
T F 11. 1 mL = 1 cm^3
T F 12. 1000 kg = 1 g
T F 13. A kilogram is bigger than a gram.
T F 14. A centimeter is bigger than a meter.
T F 15. A centimeter is bigger than a decimeter.
T F 16. A centimeter is bigger than a millimeter.
T F 17. The gram is the SI base unit for mass.
T F 18. Volume is one of the three fundamental dimensions.

Write your answers to questions 19-23.

19. A beaker of water contained 75 mL. A solid chunk of metal with a mass of 150 g was placed into a beaker of water. The volume of the water rose up, and now measured 120 mL. What was the volume of the metal?

20. Identify the property which is measured by

a. milligram...................... ____________________________
b. square centimeter........ ____________________________
c. kilometer...................... ____________________________
d. deciliter......................... ____________________________

21. Name a property of matter that does not change no matter where it is.

22. Which of the following are fundamental dimensions?

a. mass
b. weight
c. shape
d. time
e. volume
f. length

*23. The volume of a metal sphere can be changed by which one(s) of the following:

a. heating it
b. cutting a piece off
c. cooling it
d. changing its shape

Select the best choice for each of the following.

24. The thickness of a nickel is closest to
a. one meter
b. one millimeter
c. one centimeter

25. The volume of an object 2 m long by 2 m deep by 3 m high is
a. 7 m; b. 12 cm^3; c. 12 cm^2;
d. 7 m^3; e. 12 m^3

26. The volume of an egg is closest to
a. 10 cm^3; b. 100 cm^3; c. 1 m^3; d. 1 cm^3

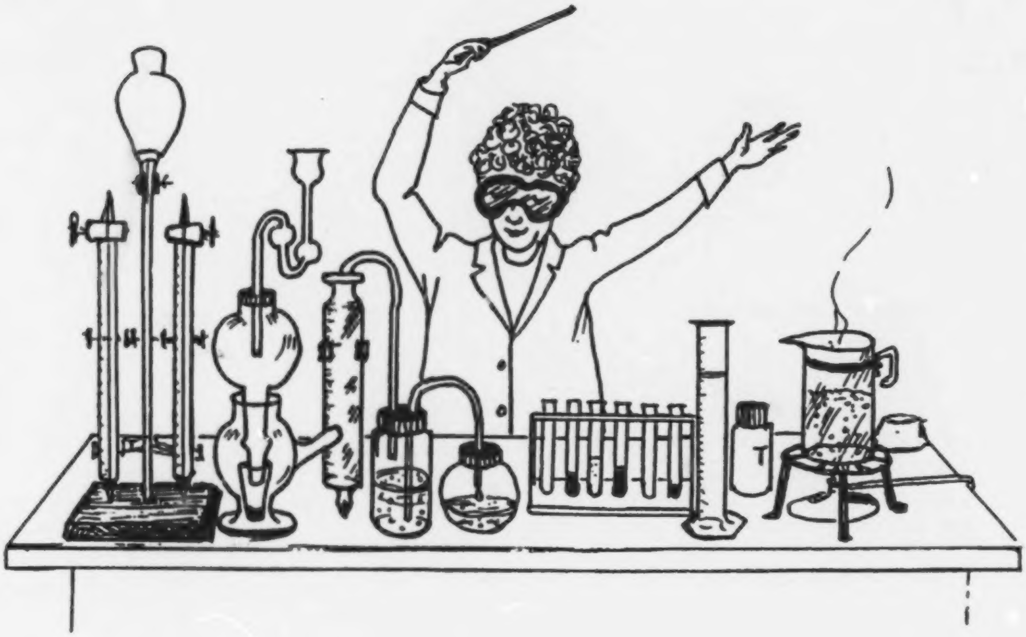
27. 1 mL has the same volume as
a. 1000 L; b. 10 cm^3; c. 100 cm^3; d. 1 cm^3; e. 0.01 L

28. Which of the following does not measure volume?
a. cubic meter
b. cubic millimeter
c. cubic decimeter
d. they all measure volume

29. The prefix which means 1/100 is
a. centi-; b. deci-; c. kilo-; d. milli-; e. mono-

*30. Room temperature is closest to
a. 0°C; b. 20°C; c. 32°C; d. 40°C; e. 70°C

*31. Body temperature is closest to
a. 100°C; b. 20°C; c. 30°C; d. 40°C; e. 50°C



3

INTRODUCTION TO CHEMISTRY

Chemistry is the science that deals with the identity of matter and the changes that matter can undergo. This chapter will look at how one kind of matter is different from another kind.

Activity 3.1 A CHEMICAL REACTION

Purpose: to recognize when a chemical change occurs
Materials: test tube, vinegar, baking soda, scoopula, balloon, funnel
Procedure: Be sure to write down your observations.

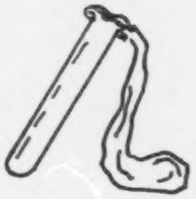
Step 1: CARRYING OUT THE REACTION

1. Put on your safety goggles.
2. Obtain a test tube, a small bottle of vinegar, a jar of baking soda, and a scoopula or a spatula.
3. Pour a little vinegar from the bottle into the test tube until the tube is about one-fourth full.
4. Your teacher will demonstrate how to carefully smell a chemical. Do not smell the chemical directly; waft the smell to your nose with your hand. Use this procedure to smell the vinegar.

5. Use the scoopula to remove about a teaspoonful of baking soda from the jar. Place the baking soda onto a piece of paper. With the scoopula, pick up a bit of the baking soda and drop it into the test tube. Shake the test tube gently back and forth to mix the materials.
6. Continue to drop bits of the baking soda into the test tube until it appears to cause no further change.
7. When you are sure that no further change is occurring, dump the contents of the test tube into the sink and flush it down with running water.
8. Thoroughly rinse the test tube and scoopula. Dry the scoopula with a paper towel.

Step 2: MAKING A HYPOTHESIS

1. You will repeat Step 1 with some changes. First, repeat Step 1, No. 2 and No. 3 (you should still be wearing your goggles) using either a test tube or the conical bottle, as instructed by your teacher.
2. As in No. 5, remove baking soda to a piece of paper.
3. Obtain a balloon. Stretch it several times to make it more flexible.
4. Your teacher will tell you how much baking soda to add. Use the funnel to pour the baking soda into the bottom of the balloon. Be sure that you do not get any of the powder inside the neck of the balloon or it will spoil the experiment.
5. Carefully hold the balloon vertically so that the powder continues to remain at the bottom of the balloon and attach the neck of the balloon firmly to the test tube or conical flask.



6. In Step 3, you will lift the bottom end of the balloon so that the baking soda falls into the vinegar. What will happen? Write your hypothesis now on a sheet of paper, sign it, and hand it in to your teacher. Do not proceed with Step 3 until your teacher gives permission to the class.

Step 3: VERIFYING YOUR HYPOTHESIS

1. Go! Dump the contents of the balloon into the vinegar.
2. Report what happened that was different from what happened in Step. 1
3. Empty the container into the sink and rinse the sink. Wash the container and scoopula. Discard the balloon. Return all the materials to where they belong. The last thing to return is your goggles.

Questions: In your Report, answer the following questions.

Q. 1 Was the vinegar still present at the end? How do you know?
Q. 2 What do you think happened to the vinegar?
Q. 3 Was your hypothesis correct? Explain.

Section 3.1 WHAT IS CHEMISTRY?

Why is sugar different from salt? What is glass? Why does garbage smell bad? How is nylon made? How can iron be stopped from rusting? The science that seeks to answer these questions is chemistry (KEHM-iss-tree).

A magician on the stage waves a magic wand over a box of matter and the material suddenly disappears. Where is it? Is it gone forever? Has it changed into something else? Chemists are magicians, too, because they can cause changes in matter. Chemists have rearranged matter to make wonderful new materials of many uses in today's world. The top of your laboratory table, the shoes you wear, the vitamins you take, the pen you use, the paint in the room, and the floor covering beneath you are just a few of the many things developed by chemists.

CHEMISTRY is the study of the identity of matter and of the changes matter can undergo.

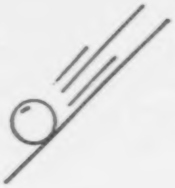
In Chapter 1, matter was defined as anything that occupies space and can be pushed or pulled. Your desk is matter and you are matter but your dreams and ideas are not matter.

Chemistry studies the matter in your car, your food, your clothes, your house, your friends, and even your dog. Chemical experiments are used to combine, separate, and rearrange particles of matter so that chemists may learn more about it. Chemists use this information to discover new knowledge and to try to make new substances which can benefit humans.

Exercise 3.1

3-1 Classify as matter or nonmatter and explain your answer.
  a. a ring of light
  b. a ring of metal

3-2 Which of the following is considered part of the study of chemistry?
  a. measuring the speed of a ball rolling downhill
  b. observing the stages in the growth of an embryo
  c. dissolving sugar in water
  d. observing the motion of planets
  e. combining hydrogen and oxygen to form water



Section 3.2 CHANGES IN MATTER

Chemists deal with two broad types of changes in matter: chemical change, and physical change.

A PHYSICAL CHANGE is a change in a property of a substance without change in its identity.

A CHEMICAL CHANGE occurs when the identity of the pure matter changes.

Examples of physical change:

..When ice melts to liquid water and then evaporates into the air, it is still water all the way, solid, liquid, or gas.

..Sugar can be gently melted into a liquid and cooled back to solid sugar again.

..Salt can be dissolved in water; when the water is boiled off, salt is left.

Examples of chemical change:

..Sugar can be heated in a pan until it burns to give smoke and a black mess. The sugar has reacted with oxygen from the air to form new materials. No sugar is present at the end of the change.

..Ethylene gas can be converted to a transparent plastic called polyethylene, which is used for plastic wrap.

..Copper ore mixtures can be reacted to form pure copper.

..Petroleum products can be reacted to form medicines.

**Q. 1 Was the change in Activity 3.1 chemical or physical?

Exercise 3.2

For questions 3-3 to 3-7, identify each as either a physical change or a chemical change:

3-3 freezing milk
3-4 burning paper
3-5 writing with a pencil on paper
3-6 melting ice cream
3-7 rusting iron

Answer to Question

Q. 1 The change in activity 3.1 was a chemical change. The vinegar was no longer present as vinegar at the end; it had changed identity.

Activity 3.2 CHEMICAL DETECTIVE WORK

Purpose: to use chemistry to identify an unknown powder knowing that it is one of three possible substances

Materials: Boraxo®, chalk, plaster of paris, aluminum foil (about 9 cm x 9 cm), scoopula, dropping bottle of vinegar, dropping bottle of methyl red indicator, test tube rack, 3 test tubes with solid stoppers, marked unknown, paper towel

Discussion: In this activity, you will carry out some physical and chemical tests to identify an unknown white powder knowing that it is one of three possible substances. The substances are Boraxo®, chalk, and plaster of paris. By first carrying out these tests on samples of these substances (the *knowns*), you will be able to identify an unknown powder which is one of those three chemicals.

Procedure: **PUT ON YOUR SAFETY GOGGLES**

Step 1: VINEGAR AND METHYL RED TESTS ON THE KNOWNS

1. Obtain the aluminum foil. Fold it to make eight squares and tear it roughly along the lines.
2. Obtain a scoopula and use it to get a sample of one of the three knowns about the size of a pencil eraser. Place it onto one of the squares of foil. With your scoopula, divide the known roughly into two piles well separated from each other.
3. Drop several drops of vinegar over one of the piles. Record your observations in the chart on the Report Sheet.
4. Drop several drops of methyl red indicator on the second pile. Record your observations as before.
5. Wipe your scoopula well with a paper towel.
6. Repeat No. 2 to No. 5 above with a second known.
7. Repeat No. 2 to No. 5 above with the third known.

Step 2: SOLUBILITY TEST ON THE KNOWNS

1. Obtain three test tube with stoppers and fill each about 2/3 full of sink water.
2. Place the test tubes into a test tube rack and mark one test tube with the name of one of the knowns, a second with another known, and the third with the last known. (Label with a piece of paper under each tube or mark the tube with a wax pencil.)
3. With the scoopula, obtain about a rice-sized grain of a known and drop it into its marked test tube. Wipe the scoopula clean and repeat for each of the other two knowns.
4. Stopper each test tube. Shake a test tube well, then the next (put them back in the right places), and then the next, on and on for several minutes. Let the three tubes sit for several more minutes.
5. Record your observations on the chart in the Report Sheet. If all the solid has disappeared from view, the solid is said to be dissolved in the liquid.

Step 3: THE UNKNOWN

1. Obtain an unknown from your teacher. Record its identification marking on the Report Sheet. Next, test it to find out the identity of your unknown.
2. Discard all solids into the trash can and flush liquids down the sink with running water. Wash your hands well. Return your goggles.

Questions:

Q. 1 Explain how you decided the identity of your unknown.

Q. 2 Fizzing and changes of color are chemical changes. Did all three tests involve chemical changes? Explain.

Q. 3 Explain, as best you can, how you organized your observations to arrive at the identification of your unknown.

Laboratory Report: Complete the Report Sheet and hand it in.

Section 3.3 ORGANIZATION IN CHEMISTRY

As the early chemists carried out observations and experiments, considerable information about matter began to accumulate so scientists tried to organize the information to make it easier to use. They looked for similarities or other connections that would help them to deal with all the little bits of information.

There are several ways by which scientific information can be organized. Two important ways are:

(1) ***CLASSIFICATION:*** *classification is the process by which bits of information are grouped together according to similarities,* such as the metals which do not corrode or the grains of sand on the beach that are rounded rather than sharp-edged.

(2) ***ORDERING:*** *ordering is arranging bits of information in a sequence.* The sequence depends upon some property, such as arranging students in a class in order of height from the shortest to the tallest.

Organization is central to the scientific process. Scientists make and record observations then organize their observatons to search for patterns and formulate hypotheses.

Activity 3.3 ORGANIZATION

Purpose: to organize a batch of words about transportation by classification and ordering
Materials: paper and pencil and a list of transportation words
Procedure:
Below is your list of numbered transportation words.

8. ferryboat;
11. ocean liner;
2. surf board;
3. hang glider;
9. commuter jet;
5. sailboat;
7. bus;
10. train;
4. car;
1. bicycle;
12. 747 airplane;
6. hot air balloon.

Cut or tear a sheet of notebook paper into 12 pieces. Write each of the numbered words on a separate piece of paper. Place the words on your desk and arrange them in some way. What criterion (what rule) did you use to organize the words? Your teacher will ask you to report this information during the class discussion of this activity.

Exercise 3.3

3-8 List the criteria you would use to organize each of the following.
- a. canned goods on the cupboard shelves.
- b. items in a toy store.
- c. all the stuff around in your room.

3-9 Name three different types of classification which can be used to group crystals in a bowl of Mystery Crystals.

Section 3.4 THE ELEMENTS

One of the first classifications of matter that chemists developed was to divide pure matter into elements and compounds.

Elements are the stuff from which all other matter is made through various combinations. When a sample of matter cannot be separated by chemical treatment into two or more simpler substances, then we know that the sample is an element.

CHEMICAL TREATMENT *means exposing a material to various substances and to different temperatures and pressures to encourage reactions.*

An ***ELEMENT*** *is matter that cannot be separated into simpler substances by chemical treatment.*

Earth
Air
Fire
Water

The ancient Greek philosophers believed that all matter was made up of various combinations of four elements: earth, air, fire and water. The conclusions of the Greeks were not based on experimentation but only on guesses. Today, we know that they were wrong about all four of their "elements." Earth, air, and water can all be broken down to simpler substances while a flame is actually a hot gas reacting and giving off light.

In the Middle Ages, little scientific activity took place. A few alchemists experimented with matter looking for a way to make gold from other elements. Their work was only qualitative at the best, and they were never able to make gold. Now we know that gold is an element; it cannot be made by chemical treatment.

If an element is gold, every part of it is gold. It can combine with other substances or be separated from them but it can't be broken down into other elements by chemical treatment.

**Q. 1 Can you name some materials which are present in elemental form in your classroom?

All matter is made up of elements and combinations of elements. How many elements do you think there are altogether? 100? 1000? 10,000?

Today, we know that there are a little over one hundred different elements. These few elements in various combinations make up all the tremendous variety of matter that exists.

COMPOUNDS *are chemical combinations of two or more elements.*

Water, salt, baking soda, and rust are examples of compounds. Water is made of hydrogen and oxygen only. Table salt is a combination of sodium and chlorine. Baking soda consists of sodium, hydrogen, carbon and oxygen. Rust is iron and oxygen. The properties of compounds are often very different from those of the elements which make them up.

PURE *matter has the same identity throughout, either as an element or a compound.*
IMPURE *matter contains material of more than one identity.*

A mixture of salt and pepper or a solution of sugar in water or a mixture of carbon and sugar is impure matter.

Chemists use the word ***SUBSTANCE*** *for any pure matter, that is, for any pure element or pure compound.*

Whereas there are only a small number of elements, there is a limitless number of compounds and new ones are being made in the laboratory every day.

Exercise 3.4

3-10 Is a chemist more likely to have samples of 200 elements or 200 compounds?

3-11 Which of the following are definitely not elements? How do you know?
a. an egg; b. rust; c. salt water; d. aluminum

3-12 Which of the choices from 3-11 are substances?

3-13 Identify the element in the following:
- a. cooking pots are made out of this lightweight metal.
- b. engagement rings often have this precious gem set into them.
- c. iron cans of food are coated with this.
- d. cooking foil is made of this safe metal.
- e. this shiny liquid is used in some thermometers.
- f. expensive jewelry often contains this yellow metal.
- g. electrical wires have this orange-brown metal inside.
- h. this gas is sometimes given to patients in the hospital to help them recover.

3-14 Can one element be made from another by chemical treatment?

3-15 Which of the following substances are compounds?
a. gold; b. sugar; c. oxygen; d. carbon dioxide.

3-16 Which of the following are pure?
a. a carrot; b. lead; c. rock candy; d. a football.

Answer to Q

Q. 1 Oxygen, nitrogen, and argon are in the air that you breathe. Your pencil has pencil lead in it; pencil lead is a form of carbon. There is probably some iron in the room. If there is any money around, the coins may contain copper, zinc, silver, and/or nickel.

Section 3.5 CHEMICAL SYMBOLS

We often use symbols as a form of shorthand such as $ for *dollars*, ♪ for *musical notes*, ♥ for a *heart*, & for *and*. Chemists also use symbols; they use them to shortcut writing long chemical names. They use a different symbol to represent each chemical element.

Usually, the chemical symbol for an element is the first one or two letters of the name of the element. The earliest names were Latin. For example, the element we now call sodium has the Latin name of natrium and was given the symbol, Na. Most of the elements, however, were not known when Latin names were used and they have been given modern names and symbols.

Each symbol of an element has only one or two letters.* The first letter is always capitalized and the second is always lower case. Some symbols of elements that you should know by heart are:

H	hydrogen	N	nitrogen
C	carbon	Na	sodium
O	oxygen	Cl	chlorine

Examples of other symbols are **Au** for gold, **Ag** for silver, **Fe** for iron, **He** for helium, **S** for sulfur, **B** for boron, and **Hg** for mercury.

Exercise 3.5

3-17 Which of the following are definitely not elements?
a. Cl; b. O; c. BH; d. Sn; e. bi; f. SO; g. N; h. Ar; i. HCl

3-18 Write the chemical symbol for nitrogen, hydrogen, carbon, chlorine, oxygen, and sodium.

Section 3.6 LAW OF CONSERVATION OF MASS

When a candle burns, does the candle just disappear? What happens to its matter?

This question is a very important one in chemistry. Can matter just disappear in a chemical reaction? A great step forward in answering this came when Antoine Laurent Lavoisier (lavv-WASS-ee-ay) (1743-1794) became the first person to carry out quantitative chemistry.**

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*The International Union of Pure and Applied Chemistry is considering the use of triple symbols for the superheavy elements.

**In addition to discovering the Law of Conservation of Mass, Lavoisier also developed a system of names for the chemical elements and wrote the first chemistry textbook. He is often called the father of chemistry. Unfortunately, he was beheaded during the French Revolution. Chemistry was too young, at that time, to support him financially so, through family connections, he obtained a position as a tax collector. Since he worked for the king, the French revolutionaries condemned him to death.

He measured the masses of reacting materials before and after he mixed them, and it was he who first stated the law which is the foundation of chemistry. It is the Law of Conservation of Mass. Lavoisier found that

total mass of everything reacting = total mass of everything produced.

As Lavoisier stated, mass is conserved during a chemical reaction. Here, "conserved" means "cannot form out of nothing and can't disappear." Mass is neither gained nor lost during any chemical reaction[1].

The reactants can be gases, liquids, and/or solids, and so can the products. When all the products are collected and massed, the sum of their masses MUST equal the mass of all the reactants.

mass in = mass out

THE LAW OF CONSERVATION OF MASS STATES THAT MATTER CAN NEITHER BE CREATED NOR DESTROYED DURING A CHEMICAL OR PHYSICAL CHANGE.

Exercise 3.6

3-19 Why is the Law of Conservation of Mass not called a theory?

3-20 What did the alchemists do?

3-21 How many grams of XY can be formed from 2.4 g X and 3.2 g Y which completely react with each other?

3-22 If 6.0 g of Q are broken down into A and B, and if the mass of B is found to be 3.5 g, what is the mass of A?

3-23 Jason carefully measured the mass of 3.0 g of zinc and placed it into a test tube containing exactly 10.0 g of hydrochloric acid. The reaction mixture became hot and bubbled. After the experiment, Jason measured the mass of the contents of the test tube and found that it was less than 13.0 g. Should Jason conclude that he has found an exception to the Law of Conservation of Mass? Why?

3-24 Lavoisier is called the father of modern chemistry. What single great discovery gave him this honor? What experimental technique made this possible?

Activity 3.4 LAW OF CONSERVATION OF MASS

Purpose: to test the Law of Conservation of Mass

Materials: ice cube, small beaker, plastic bag and tie, crushed chalk, vinegar, 10 mL graduated cylinder, laboratory balance.

Procedure: Wear safety goggles. Before you leave the laboratory, scrub your hands and under your fingernails with soap and water.

Step 1:

1. Place an ice cube into a beaker.
2. Measure the mass of the ice cube and beaker.
3. Place the beaker into some hot water. Allow the ice cube to melt.
4. Remove the beaker and dry the outside.
5. Measure the mass of the beaker plus the melted ice cube.

---

[1] According to Einstein's theories, minute conversions of mass to energy take place during chemical reactions; these are too small to measure on a laboratory balance. Also, changes in mass take place during radioactive change.

Step 2:

1. Place about 5 cm^3 of crushed chalk into a plastic bag. Twist it closed at the top with a tie.
2. Measure the mass of the tied-up baggie with the chalk.
3. Place about 5 mL of vinegar into a 10 mL graduated cylinder.
4. Measure the mass of the cylinder with the vinegar.
5. Open the baggie, pour the vinegar into the baggie and immediately twist it tightly closed at the top. Wait until the reaction stops.
6. Find the mass of the baggie and of the graduated cylinder together on the balance.
7. How did you know when the reaction between the chalk and vinegar stopped?
8. Why should the baggie be closed as soon as you add the vinegar?

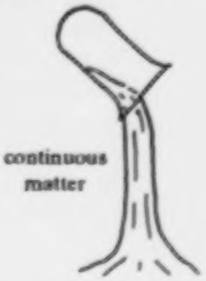
Laboratory Report: Write a laboratory report to include a hypothesis and conclusion.

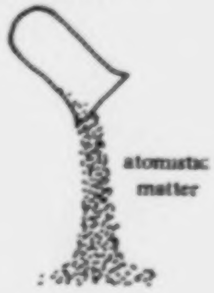
Section 3.7 DALTON'S ATOMIC THEORY

Picture a genie tearing a sheet of aluminum foil in half, and then in half again, and then again and again. If the genie goes on tearing the aluminum foil into smaller bits of aluminum, will the genie finally reach ultimate bits of aluminum which cannot be torn further and yet still be aluminum?

Until the nineteenth century, almost nobody thought that matter was made up of the little bits we now call atoms. They believed that aluminum, for example, was sort of a stream; no matter how small a portion was taken, it was always aluminum.

John Dalton (1766-1844) was an English school teacher who was fascinated by chemistry and conducted many experiments. In 1803, he announced his atomic theory.





The key ideas of Dalton's Atomic Theory still hold. His theory included the following.

1. Matter is made up of atoms unique to each element.
2. Compounds are built out of atoms of different elements.

However, Dalton believed that atoms were hard, solid, indivisible spheres. Today, we know that atoms are made up of internal parts which can be separated.

Dalton's theory was not immediately accepted by all. In those days, less than 200 years ago, atoms seemed like a very far-fetched idea. Nobody could see atoms, not even through a microscope. Matter looked as if it were continuous. Acceptance of Dalton's theory came very slowly. Today, we even know, thanks to the scanning electron microscope and other marvellous instruments, how layers of atoms look and where atoms are in the layers. Atoms are no longer a theory; they are a fact. (The parts of an atom, however, are still known only theoretically.)

Dalton's Atomic Theory explains why mass is conserved in chemical reactions. If matter is composed of individual atoms which are just rearranged during a chemical change, then the total mass before and after must be conserved.

Exercise 3.7

3-25 Are there any atoms visible to the naked eye?

3-26 How many years ago did Dalton publish his atomic theory?

3-27 According to Dalton, in what way do the atoms of elements differ from the atoms of compounds?

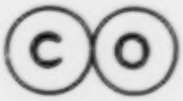
Section 3.8 COMPOUNDS

Dalton said that ***COMPOUNDS** are combinations of atoms of different elements.*

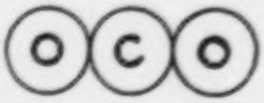
This is a definition of a compound in terms of the atoms that make it up. Thus, salt is a compound of sodium and chlorine. Carbon dioxide is made up of carbon and oxygen. Sugar is made of carbon, hydrogen, and oxygen. Sulfuric acid always has 2 atoms of hydrogen for every 4 atoms of oxygen for each 1 atom of sulfur.

However, carbon monoxide and carbon dioxide are both made up of carbon and oxygen. Dalton recognized that two different compounds could be made up of the same elements, and he could explain it. The reason that these two compounds are different is that carbon dioxide always has two atoms of carbon to one atom of oxygen whereas carbon monoxide only has one atom of carbon per atom of oxygen.

carbon dioxide	2 atoms O per one atom C	different compounds
carbon monoxide	1 atom O per one atom C	



carbon monoxide



carbon dioxide

THE IDENTITY OF A COMPOUND DEPENDS ON THE ELEMENTS IN IT AND ON THE RATIO OF THE ATOMS OF THOSE ELEMENTS.

We know today that, in water, there are always two atoms of hydrogen to one atom of oxygen. In one drop of water, there may be billions upon billions of hydrogen and oxygen atoms but there are always 2 atoms of hydrogen for every 1 atom oxygen. Hydrogen peroxide has 2 atoms of hydrogen for every 2 atoms of oxygen; it is not the same as water.

Some elements can combine with each other in only one ratio. There is only one combination of sodium and chloride that can form a compound; table salt always has one atom of sodium per one atom of chlorine. There is only one compound of atoms of calcium and oxygen (lime). Aluminum nitride always has 1 atom of aluminum per 3 atoms of nitrogen.

Activity 3.5 MODELS OF CHEMICALS

Purpose: to make models of compounds

A scientific model is a real structure which pictures something we cannot see. A model usually leaves out details which are not needed for the desired picture.

Materials: spheres to stand for 9 hydrogen atoms, 3 oxygen atoms, 1 nitrogen atom, and nine sticks or toothpicks to use as connectors

Procedure:

1. Make three water particles. Each water particle has two atoms of hydrogen per one atom of oxygen. Connect the atoms with the toothpicks or sticks. The hydrogens in any compound can never be connected to each other.
2. Ammonia is made up of three atoms of hydrogen per one atom of nitrogen. Make a model of ammonia.

Questions

Q. 1 a. How many atoms of hydrogen are present for each atom of oxygen in water?
  b. How many atoms of oxygen are present in the three particles of water?
  c. How many atoms of hydrogen are present in the three particles of water?
  d. For every 10 atoms of hydrogen in water, how many atoms of oxygen are present?

Q. 2 For the compound, ammonia,
  a. how many hydrogen atoms are there per one nitrogen atom?
  b. Suppose that you had five particles of ammonia. How many nitrogen atoms would you have? How many hydrogen atoms?

Q. 3 Name three ways discussed so far in which scientists organize their knowledge.

Q. 4 Describe briefly how this model differs from a real atom.

Exercise 3.8

3-28 A substance, hydrogen chloride, (HIGH-droh-jen KLOR-eyed) is made up of combinations of one atom of hydrogen per atom of chlorine (KLOR-een).
  a. If there are 1000 atoms of hydrogen in a sample of hydrogen chloride, how many atoms of chlorine are present?
  b. Given one million atoms of chlorine in hydrogen chloride, how many atoms of hydrogen are present?

3-29 Carbon dioxide has one atom of carbon present for every two atoms of oxygen. If there are one billion billion atoms of carbon in a sample of carbon dioxide, how many atoms of oxygen must also be present?

3-30 Carbon monoxide has one atom of carbon per atom of oxygen. Carbon dioxide has one atom of carbon per two atoms of oxygen. Does this violate the Atomic Theory?

3-31 Table salt (sodium chloride) has one atom of sodium per each atom of chlorine.
  a. Does the number of atoms of sodium per atom of chlorine in sodium chloride ever change?
  b. If a quantity of table salt is doubled from 100 g to 200 g, what happens to the number of sodium atoms per each chlorine atom in sodium chloride?

Section 3.9 STATES OF MATTER

Depending on the temperature, there are three forms in which any substance may be found on our Earth, namely *solid, liquid or gas.*

Solid, liquid, and gas are called the three physical
STATES OF MATTER*

When you are looking at an object, how do you know if it is a solid, liquid, or gas?

Solid: retains its shape regardless of the container.
Liquid: takes the shape of the container and fills it from the bottom up.**
Gas: completely fills the container

The above descriptions are based on what can be seen by eye. What is it like deep within? How are the particles of matter, invisible to our eyes, arranged? We cannot see the particles even with the aid of an ordinary microscope. X-rays and electron microscopes have told us much about the location of the particles in solids.

Following are drawings of the way that scientists believe the particles of matter are arranged in each physical state. The sub-microscopic model is well supported by scientific studies.

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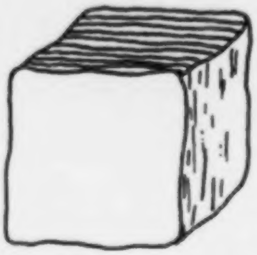
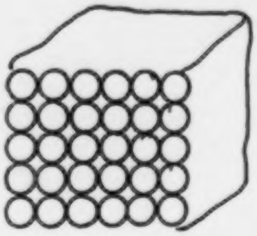
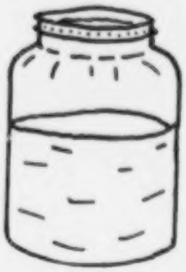
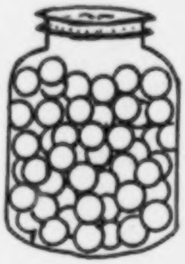
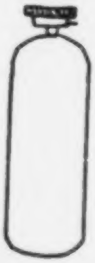
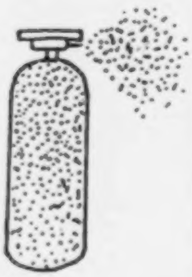
*Other states of matter can exist under special circumstances

**In outer space, surface tension pulls a free-floating liquid into a sphere.

 	Solid Particles are in a regular arrangement and are touching
 	Liquid Particles are in an irregular arrangement and are touching.
 	Gas Particles are in an irregular arrangement and are far apart.

All gases are transparent and most, but not all, are colorless.

Exercise 3.9

3-32 a. Draw a picture of what you would see if you looked at a jar of ice cubes, a jar partly filled with liquid water, and a sealed jar of water vapor.

b. How would your drawings need to be altered if you had the power to see particles as tiny as atoms? Draw each water particle as a little circle.

Chapter Three Review

Vocabulary

- Chemistry
- Physical Change
- Element
- Atom
- Compound
- Dalton's Atomic Theory
- Chemical Change
- Substance
- States of matter
- Chemical symbols
- Law of Conservation of Mass

Use the vocabulary terms above to complete each sentence below. Each vocabulary terms can be used only once.

1. When popsicles are frozen, we say that a ____________________ has occurred.
2. ____________________ : the branch of science which studies the identity of matter and the changes it undergoes
3. ____________________ : an element or a compound
4. ____________________ : the smallest particle of matter
5. ____________________ : one or more substances undergo a reaction
6. ____________________ : a substance that cannot be broken down into simpler substances
7. ____________________ : matter is made of tiny particles
8. ____________________ : the chemist's shorthand
9. ____________________ : matter cannot be gained or lost during a chemical reaction
10. ____________________ : a substance composed of more than one element
11. Water and ice are different ____________________ .

Applications

1. Label the processes below as: "physical change", "chemical change", or "neither one".
   - a. melting snow
   - b. molding clay
   - c. grinding salt to a powder
   - d. lighting a match
   - e. mixing lemonade
   - f. growing a seed
   - g. digesting a cookie
   - h. planning a picnic
   - i. burning gasoline in your car
   - j. counting numbers
   - k. cutting paper
   - l. coloring eggs

The following questions are multiple choice; choose the best answer for each.

2. Which of the following is not an element?
   a. Cl; b. O; c. NO; d. Na.

3. Which of the following is not considered part of Dalton's Theory?
   a. water is made up of atoms
   b. atoms can be broken apart
   c. atoms combine to form compounds
   d. oxygen atoms are different from hydrogen atoms

4. Which of the following might change during a chemical reaction?
   a. the number of atoms
   b. the total mass before and after the experiment
   c. the kinds of atoms
   d. the number of substances present before and after the experiment

5. Which of the following is not a physical change?
   a. decomposing; b. freezing; c. boiling;
   d. melting; e. condensing.

6. Who was the first person to perform quantitative measurements in chemistry using a balance.
   a. Dalton; b. Lavoisier; c. Aristotle; d. Newton; e. Democritus.

7. The process of burning causes some substances to lose mass, some to gain mass, and leaves the mass of still others unaffected. The Law of Conservation of Matter is obeyed in
   a. the third case only
   b. the second and third cases
   c. all three cases
   d. no case where burning is involved

The following questions require short answers.

8. In order to organize data, one must look for ________________________ .

9. Table salt is a compound made of the elements sodium and chlorine. For each sodium atom, there is one chlorine atom. Given a sample of table salt containing three billion billion atoms of chlorine, how many atoms of sodium are present?

10. What could you do in the laboratory to change a sugar crystal
    a. physically?
    b. chemically?

11. Use the information in your textbook to:
    a. correct any mistakes in the chemical symbols below.
    b. write the name of the element which is represented by each corrected symbol.
    (1) O (2) N (3) CL (4) na (5) H (6) c

12. How much of the compound QT can be synthesized by completely combining 4.0 g of Q and 16.0 g of T?

13. If you froze 25 grams of water, would you expect the mass of ice to be greater than 25 grams? Explain your answer.

14. In the kitchen, how might you test the statement, "When sweetened gelatin solidifies, a physical change has occurred?"

15. Kevin wants to prepare 26.3 g of DY which he makes by combining D and Y together. He has 3.8 g of D.
   a. What quantity of Y must he purchase?
   b. On what law did you base your calculation?

16. a. If Michael completely reacts 657.6 g of E with 22.0 of Z to produce EZ, how much EZ can he expect to obtain?
   b. Which scientist discovered the rule on what your answer is based?

17. Sulfur atoms combine with hydrogen atoms to form the compound hydrogen sulfide (which smells like rotten eggs). Each sulfur atom reacts with two hydrogen atoms.
   a. How many hydrogen atoms are there per sulfur atom?
   b. Given three billion billion atoms of hydrogen,
      (1) how many atoms of sulfur combine with them to form hydrogen sulfide?
      (2) how many hydrogen sulfide particles are formed?

18. Which one of the following does not belong in the classification? What is the criterion for belonging?
   a. blue; b. red; c. dark; d. yellow

19. Which of the following does not belong in the sequence? What is the criterion for the order of numbers?
   a. 2, 4, 6, 8, 10
   b. 2, 4, 5, 7, 9
   c. 5, 7, 9, 11, 13
   d. 101, 103, 105, 107, 109

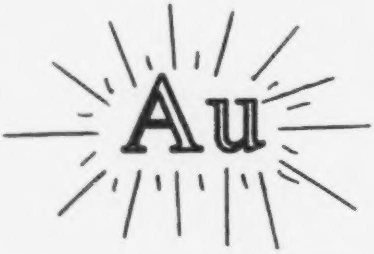
20. a. Compare the distance between particles of a solid, liquid, and gas.
   b. How orderly are the particles of a solid compared to a liquid and a gas?

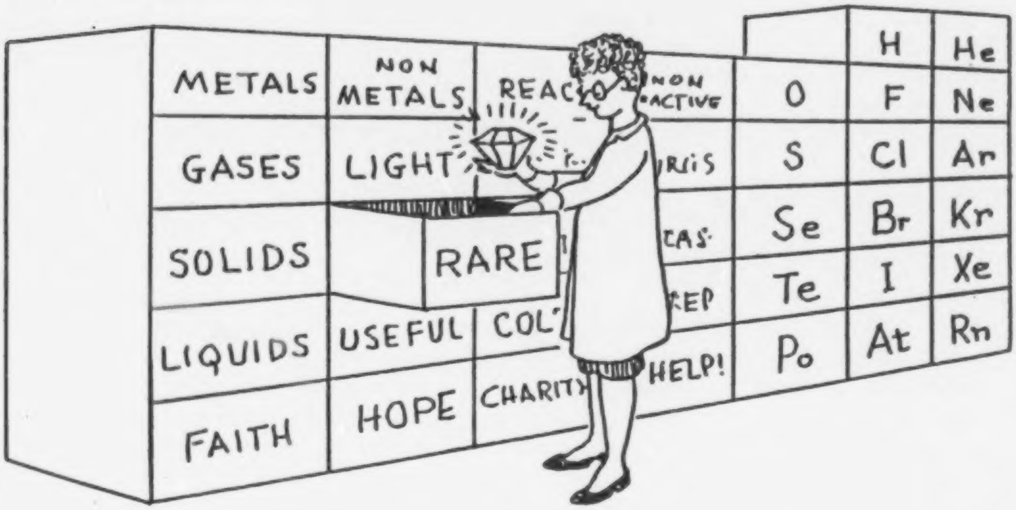
21. Which of the choices below is not a chemical substance? Explain.
   a. carbon.
   b. carbon dioxide.
   c. salt solution.
   d. neither b. nor c. are correct choices.

22. Is it possible to have two different compounds of the same elements? Explain.

23. Whose discoveries came first, Lavoisier or Dalton? Near to the beginning of which century did they occur?

ALL THAT GLITTERS IS NOT




METALS
NON METALS
REAC
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GASES
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4

Activity 4 . 1 ORGANIZED INFORMATION

Purpose: to observe the use of organized information in human knowledge
Discussion: Information can be organized into arrangements that (1) classify and/or (2) order the data. The human brain can use to its advantage the patterns that it perceives.
Materials: paper and pencil
Procedure: Your teacher is going to write a code on the blackboard for numbers 1 to 9. You have sixty seconds to memorize it. Then, you will be given a task using those numbers.
Report: A report is not required for this activity.

Section 4 . 1 DMITRI MENDELEYEFF AND THE PERIODIC TABLE

Do chemists memorize the properties of all the existing elements and their millions of compounds? Of course not! To simplify the task of working with this vast quantity of information, chemists search for connections. The connections are in the form of (1) similarities which allow classifications and/or (2) arranging the data in some kind of order. In these ways, information is organized to become meaningful.

By the middle of the 1800's, scientists had identified about 70 elements and were busily gathering data on their properties. They needed some way to organize all the information.

Mendeleyeff (men-dell-A-eff), a Russian scientist, had long been seeking a way to do this. He was so engrossed in this venture that he would make up cards with the known elements and all their properties on them and take them to parties with him. There, he would ask the noble men and ladies to work with him on arranging the data. In 1869, Mendeleyeff published his table of the elements.

In his table, Mendeleyeff first arranged the elements in order of the mass of each atom. Using the elements known today, this would look like

H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K....

Mendeleyeff noticed that the properties of these elements changed regularly in this row. As atomic mass increased, melting point gradually increased, then gradually decreased, then started to increase again, and so on. However, there were some sharp changes in properties just before lithium (Li), sodium (Na), and potassium (K). These three metals are alike in many ways. They are very reactive, soft metals which react in much the same way with water, with oxygen, and with chlorine. Mendeleyeff broke off the ribbon of elements at sodium and began a new row by placing sodium under lithium. He broke the ribbon with potassium and began another new row by placing potassium under sodium. Using the elements known today, this would look like

H	**He**	**Li**	**Be**	**B**	**C**	**N**	**O**	**F**	**Ne**
		Na	**Mg**	**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
		K.....							

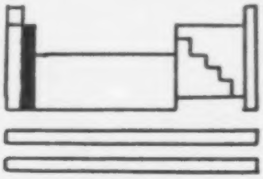
When he did this, not only did the the elements in the lithium column all have similar chemical properties but the elements in each of the other columns also were grouped by similar properties. Even though Mendeleyeff didn't know all the elements, he was still able to work out the table so that all the elements in the same columns (groups) had similar properties. His table caused the elements to appear as rows in order of atomic mass and columns (groups) with elements having similar properties.

Each row had gradually changing properties which repeated itself in the next row. Repeating changes in properties are said to be periodic so Mendeleyeff's table is called a periodic table.

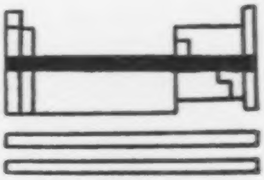
Because Mendeleyeff knew only about seventy elements, he found that he had to leave spaces in some places because the properties were otherwise out of line. Mendeleyeff predicted that elements would be discovered for these spaces and he predicted their properties based on the ones near them. When two such elements were discovered not long afterwards with the properties that Mendeleyeff predicted, his fame was made.

Look at the arrangement of the elements in the modern periodic table on the next page. The atomic masses are the numbers that are given with decimal places in each box for an element.*

In the modern periodic table, the vertical columns in which the elements have similar chemical properties are called **FAMILIES** or **GROUPS** or simply **COLUMNS**. The horizontal rows in the table are called **PERIODS**.



column



period

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*Atomic masses for some elements are now known to as many as six decimal places. In this table, they are all rounded off to two decimal places.

PERIODIC TABLE OF THE ELEMENTS

Atomic weights conform to the 1961 values of the Commission on Atomic Weights.

KEY
Atomic Mass (Weight) — 12.01115
Symbol — C
Atomic Number — 6

Transition Elements

GROUPS

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIII
1	1.00797 H 1																1.00797 H 1	4.0026 He 2
2	6.939 Li 3	9.0122 Be 4											10.811 B 5	12.01115 C 6	14.0067 N 7	15.9994 O 8	18.9984 F 9	20.183 Ne 10
3	22.9898 Na 11	24.312 Mg 12											26.9815 Al 13	28.086 Si 14	30.9738 P 15	32.064 S 16	35.453 Cl 17	39.948 Ar 18
4	39.102 K 19	40.08 Ca 20	44.956 Sc 21	47.90 Ti 22	50.942 V 23	51.996 Cr 24	54.9380 Mn 25	55.847 Fe 26	58.9332 Co 27	58.71 Ni 28	63.54 Cu 29	65.37 Zn 30	69.72 Ga 31	72.59 Ge 32	74.9216 As 33	78.96 Se 34	79.909 Br 35	83.80 Kr 36
5	85.47 Rb 37	87.62 Sr 38	88.905 Y 39	91.22 Zr 40	92.906 Nb 41	95.94 Mo 42	(99) Tc 43	101.07 Ru 44	102.905 Rh 45	106.4 Pd 46	107.870 Ag 47	112.40 Cd 48	114.82 In 49	118.69 Sn 50	121.75 Sb 51	127.60 Te 52	126.9044 I 53	131.30 Xe 54
6	132.905 Cs 55	137.34 Ba 56	57-71	178.49 Hf 72	180.948 Ta 73	183.85 W 74	186.2 Re 75	190.2 Os 76	192.2 Ir 77	195.09 Pt 78	196.967 Au 79	200.59 Hg 80	204.37 Tl 81	207.19 Pb 82	208.980 Bi 83	(210) Po 84	(210) At 85	(222) Rn 86
7	(223) Fr 87	(226) Ra 88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118

Numbers in parentheses are mass numbers of most stable or most common isotope.

Lanthanide Series

138.91 La 57	140.12 Ce 58	140.907 Pr 59	144.24 Nd 60	(147) Pm 61	150.35 Sm 62	151.96 Eu 63	157.25 Gd 64	158.924 Tb 65	162.50 Dy 66	164.930 Ho 67	167.26 Er 68	168.934 Tm 69	173.04 Yb 70	174.97 Lu 71

Actinide Series

(227) Ac 89	232.038 Th 90	(231) Pa 91	238.03 U 92	(237) Np 93	(242) Pu 94	(243) Am 95	(247) Cm 96	(247) Bk 97	(249) Cf 98	(254) Es 99	(253) Fm 100	(256) Md 101	(254) No 102	(257) Lw 103

There are presently two systems of numbering for the columns in the table. The newer system simply numbers them in order from 1 starting at the left. The older system uses Roman numerals and divides the columns into A and B groups. In the above table, both systems are shown.

As of March, 1997, the names and symbols of elements 104-109 are being decided by the International Union of Pure and Applied Chemistry. The most likely choices are: Element 104, Rutherfordium (symbol Fr) ; Element 105, Dubnium (symbol Db) ; Element 106, Seaborgium (symbol Sg) ; Element 107, Bohrium (symbol Bh) ; Element 108, Hassium (symbol Hs) ; and Element 109, Meitnerium (symbol Mt) . Elements 110, 111, and 112 have been synthesized but are still unnamed. Only a few atoms each of Elements 104-111 have ever been synthesized and they lived for only a few seconds.

ALPHABETICAL LIST OF THE ELEMENTS

Symbol	Name	Atomic Number	Symbol	Name	Atomic Number
Ac	Actinium	89	Hg	Mercury	80
Al	Aluminum	13	Mo	Molybdenum	42
Am	Americium	95	Nd	Neodymium	60
Sb	Antimony	51	Ne	Neon	10
Ar	Argon	18	Np	Neptunium	93
As	Arsenic	33	Ni	Nickel	28
At	Astatine	85	Nb	Niobium	41
Ba	Barium	56	N	Nitrogen	7
Bk	Berkelium	97	No	Nobelium	102
Be	Beryllium	4	Os	Osmium	76
Bi	Bismuth	83	O	Oxygen	8
B	Boron	5	Pd	Palladium	46
Br	Bromine	35	P	Phosphorus	15
Ca	Calcium	20	Pt	Platinum	78
Cd	Cadmium	48	Pu	Plutonium	94
Cf	Californium	98	Po	Polonium	84
C	Carbon	6	K	Potassium	19
Ce	Cerium	58	Pr	Praseodymium	59
Cs	Cesium	55	Pm	Promethium	61
Cl	Chlorine	17	Pa	Proactinium	91
Cr	Chromium	24	Ra	Radium	88
Co	Cobalt	27	Rn	Radon	86
Cu	Copper	29	Re	Rhenium	75
Cm	Curium	96	Rh	Rhodium	45
Dy	Dysprosium	66	Rb	Rubidium	37
Es	Einsteinium	99	Ru	Ruthenium	44
Er	Erbium	68	Rf	Rutherfordium	104
Eu	Europium	63	Sm	Samarium	62
Fm	Fermium	100	Sc	Scandium	21
F	Fluorine	9	Se	Selenium	34
Fr	Francium	87	Si	Silicon	14
Gd	Gadolinium	64	Ag	Silver	47
Ga	Gallium	31	Na	Sodium	11
Ge	Germanium	32	Sr	Strontium	38
Au	Gold	79	S	Sulfur	16
Hf	Hafnium	72	Ta	Tantalum	73
Ha	Hahnium	105	Tc	Technetium	43
He	Helium	2	Te	Tellurium	52
Ho	Holmium	67	Tb	Terbium	65
H	Hydrogen	1	Tl	Thallium	81
In	Indium	49	Th	Thorium	90
I	Iodine	53	Tm	Thulium	69
Ir	Iridium	77	Sn	Tin	50
Fe	Iron	26	Ti	Titanium	22
Kr	Krypton	36	W	Tungsten	74
La	Lanthanum	57	U	Uranium	92
Lr	Lawrencium	103	V	Vanadium	23
Pb	Lead	82	Xe	Xenon	54
Li	Lithium	3	Yb	Ytterbium	70
Lu	Lutetium	71	Y	Yttrium	39
Mg	Magnesium	12	Zn	Zinc	30
Mn	Manganese	25	Zr	Zirconium	40
Md	Mendelevium	101			

The periodic table is one of the great organizing patterns of science. Although Mendeleyeff based it entirely on atomic masses and on chemical properties, it has led to theoretical understandings far beyond what Mendeleyeff dreamed.

Exercise 4.1

4-1 a. What was the first criterion by which Mendeleyeff arranged his elements? Is this a criterion which arranges the elements in order of size of some property or does it arrange the elements according to their similarities?
b. What criterion did Mendeleyeff use to break up his ribbon of elements and start again under the first one? Is this a classification criterion or an ordering criterion?

4-2 In Mendeleyeff's day, not all of the elements had yet been discovered. His table was incomplete. How did he adjust for this?

4-3 a. What is meant by a column in the periodic table?
b. What is meant by a period in the periodic table?

Section 4.2 PERIODS

Look at the modern periodic table for the answers to the following.

**Q. 1 How many periods are there?

**Q. 2 Period One is the first period is at the top of the table. How many elements are in Period One?

**Q. 3 The integers accompanying each element are called atomic numbers. They will be explained later. For now, what can you say about the atomic numbers besides the fact that they are integers?

**Q. 4 Where are the elements with atomic numbers 57 to 71? There isn't enough room to get them into their proper place on an ordinary page. These elements are called the lanthanides.

**Q. 5 Where are the elements with atomic numbers 89-103? These elements are called the actinides.

**Q. 6 Periods Four, Five, and Six each have more elements than Periods Two and Three. These additional elements appear after the second column. How many additional elements are in each period? All of the additional elements together but not counting the lanthanides or actinides are called the transition elements. How many transition elements are there?

**Q. 7 How many elements are shown in all?

**Q. 8 Which has more elements, Period One or Period Seven?

**Q. 9 In each column, going from Period One to Period Seven, does the atomic mass increase, decrease, or stay the same?

For your convenience, the answers to the above Q's are listed below.

Answers to Q's

Q. 1 There are seven periods.

Q. 2 There are two elements in Period One.

Q. 3 The elements in the modern periodic table are arranged in the order of the atomic numbers. Each element has its own atomic number. The higher the atomic number, the greater the atomic mass of the element (with a few exceptions).

Q. 4 They are in the row directly below the seventh period.

Q. 5 They are the bottom row on the page.

Q. 6 There are ten additional elements in each period giving a total of thirty transition elements.

Q. 7 103 elements are shown in all. (Today, we recognize 105 elements. The names of the last two are currently in dispute, and the Russian claim for element 106 is being judged).
Q. 8 Period Seven has more elements.
Q. 9 The atomic mass in each column increases from Period One to Period Seven.

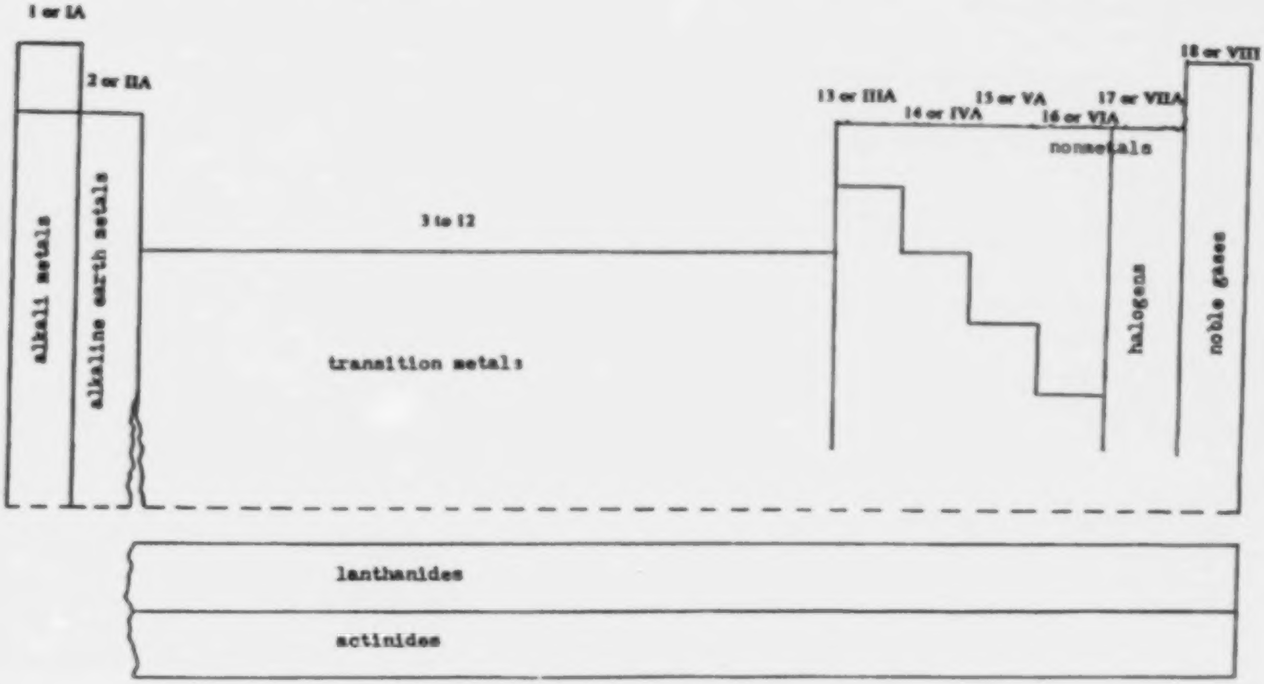
The element present in the greatest abundance of atoms in the universe is hydrogen. On our earth, oxygen is the most abundant followed by silicon and then hydrogen.

There are presently two systems for numbering the columns in the periodic table. Both are shown in the diagram of the table below. The columns labeled with a number and the letter A are called the Main Group elements. The **Main Group** columns are 1A to VIIIA or, in the other numbering system, columns 1-2, 13-18. All of the other elements are either transition elements, lanthanides, or actinides.

Exercise 4.2

4-4 a. How many elements are known today?
b. Which element has the greatest number of atoms in the universe? On the earth?

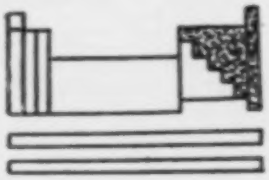
4-5 a. How many periods are in the modern periodic table?
b. In which period are the actinides found?
c. In which periods are the transition elements found?
d. In which period are the lanthanides found?
e. Using the Roman numeral and the letter A, identify the columns which hold the Main Group elements.


1 or IA
2 or IIA
13 or IIIA
14 or IVA
15 or VA
16 or VIA
17 or VIIA
18 or VIII
nonmetals
3 to 12
alkali metals
alkaline earth metals
transition metals
halogens
noble gases
lanthanides
actinides

Activity 4.2 THE PERIODIC TABLE

Purpose: to get to know the periodic table.
Materials: pencil and paper, blank periodic table
Procedure: As you study the elements introduced in this chapter, write the atomic number, symbol, and special physical properties in the space for that element in the blank periodic table. You will learn the meaning of the atomic number in the next chapter; at present, it just tells you the order of the elements. When a new element is introduced from here on, record it in your table. At present, place the elements lithium, sodium, and potassium into the table.

Section 4.3 METALS AND NONMETALS



In the modern periodic table, you will find a steplike line which runs diagonally from the top to the lower right of the table. This dark zigzag line roughly separates metals from nonmetals. The elements to the left of the diagonal line are metals while those to the right are nonmetals. Certain elements along the jagged line have some metallic and some nonmetallic properties and are called metalloids.*

What is a metal? Picture a metal in your mind. Are you seeing a hard, shiny material which can bend without breaking? The distinctive properties of the metals compared to nonmetals follow.

Metals	Nonmetals
special luster (the unique shiny surface of metals)	no metallic luster
all solids except for mercury	gas, liquid, or solid
good conductors of heat and electricity	poor conductors of electricity
DUCTILE (can be stretched into wires)	*BRITTLE* (solid can't be stretched, breaks on bending)
MALLEABLE (can be bent or dented)	

Exercise 4.3

4-6 Separate the following properties into two lists, one for metals and one for nonmetals:

ductile
break on bending
metallic luster
good conductor of electricity
nonductile
can be bent
brittle
many gases
mostly solids,
poor conductor of electricity
dull surface of solids

4-7 Identify the following elements located in the third period of the periodic table as metals or as nonmetals.

a. chlorine, Cl; b. potassium, K; c. sulfur, S

4-8 Compare the number of metals to nonmetals. Do not count the elements in column VIIIA (column 18).

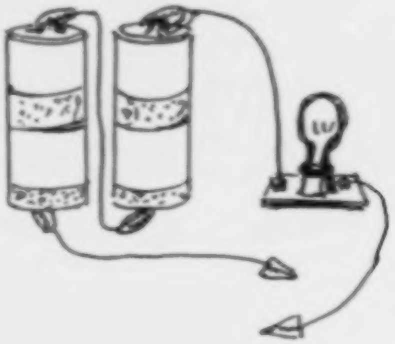
---

*The metalloids include boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), tellurium (Te), polonium (Po), and astatine (At).

Activity 4 . 3 METALS VERSUS NONMETALS

Purpose: to identify metals and nonmetals by means of their physical properties
Materials: small samples of aluminum, carbon, sulfur, copper, and zinc; sandpaper, 2 D cells, wires with alligator clips, milliamp meter or low-voltage electric bulb on base, hammer and board, scoopula.
Procedure: Wear your goggles. Do not handle anything with your fingers; use a scoopula, tongs, or tweezers. Wash your hands and scrub under your fingernails before leaving the laboratory.

Examine each of the elements for luster, malleability, and whether it conducts electricity as described below. Then, decide if the element is a metal or nonmetal.



Step 1: LUSTER
Look for metallic luster. Sometimes, metals become coated with oxides. If you sand them a little, the oxide is scraped away and you can see the luster. Don't bother trying this on a powder or crystals.

Step 2: MALLEABILITY
Find out if the sample can be bent. Or, place it on the wooden board and bang it once with the hammer to see if a dent appears in the sample.

Step 3: CONDUCTIVITY
1. Make up a chart listing all of the elements to be tested, with places to record your data You will need columns for luster, malleability, and conductivity. Include a final column which states whether it is a metal or nonmetal.
2. To test for conductivity, use 2 D cells, wires, and a milliamp meter or low-voltage bulb on base. See the diagram above at the right. Do not hold the wire to the metal for more than a brief touch; look quickly at the meter to see if it conducts or at the lamp to see if it lights or gets warm. If using a bulb instead of a meter, you need to hold the wire to the metal a little longer to give the bulb time to heat up.

Step 4: THE PERIODIC TABLE
Locate on the periodic table each of the elements you tested and write them into it.
Conclusion: Write your conclusions.

Section 4 . 4 COLUMNS (GROUPS OR FAMILIES)

Recall that Mendeleyeff lined up the elements not only in order of mass but so that those with similar chemical properties were in the same column. We will look briefly at three families (columns) of elements: (1) a reactive metal family, (2) a reactive nonmetal family, and (3) a nonreactive family.

(1) ALKALI METALS: a reactive metal family located in the first column at the left of the table (IA or 1).

Can you imagine a metal that reacts with water! When placed into water, these metals immediately burst into a flame, sometimes explosively as they react with the water. The reason why you have probably never seen any of these metals is that they are so very reactive.

Once they react with another element, they form very stable compounds like ordinary table salt, sodium chloride. Yet, these metals are soft like putty and can be cut with a table knife.

All of the alkali metals are found in nature only as parts of compounds, never as free elements.

Fill in the alkali metals on your periodic table.

IA or 1
3 **Li** Lithium
11 **Na** Sodium
19 **K** Potassium
37 **Rb** Rubidium
55 **Cs** Cesium
87 **Fr** Francium

4.4 B. THE HALOGENS (HAY-luh-jenz): a reactive nonmetal family located in the second column from the right (VIIA or 17).

The halogens are all reactive in the elemental state but stable when in compounds. You are familiar with table salt, sodium chloride, and sodium fluoride or stannous fluoride which you take in your mouth in toothpaste to protect your teeth.

Neither fluorine (F) nor chlorine (Cl) are gases that you would like to meet in the elemental state. Fluorine is the most reactive nonmetal known. It even reacts with glass and it causes terrible burns on the skin. Until the invention of plastics, the only container that could hold it was made of wax. Can you imagine what might have happened on a hot day?

Chlorine (Cl) is a yellow gas that was used as a poison gas in World War I. You are probably familiar with its smell in liquid bleach.

Bromine (Br) is a red liquid. It is one of the only two liquid elements known; mercury (Hg) is the other one.

Iodine (I) is a dark gray solid which is necessary to the human diet to prevent goiter, a disease of the thyroid gland. Table salt (sodium chloride) can be purchased containing 1% of sodium iodide (a compound of iodine that can be safely eaten) as a protection against goiter.

Place the halogens into your periodic table. Develop a system for your table to show which elements are solids, which gases, and which liquids. Use it for the elements you have on your table.

VIIA or 17
9 **F** Fluorine
17 **Cl** Chlorine
35 **Br** Bromine
53 **I** Iodine
85 **At** Astatine

4.4 C. NOBLE GASES: a nonreactive gaseous family found at the far right of the table (VIIIA or 18).

The noble gases are unique because they are very unreactive. They are the only elements that exist as separated single atoms in the elemental state. Helium (He) is the lightest of the noble gases and is used in balloons and dirigibles. (Hydrogen has better lifting power but it reacts explosively with oxygen if it is sparked.) Helium is the second most abundant element in the universe, following hydrogen which is the most abundant.

Another noble gas which you might know is neon, (Ne) the gas which gives the red color in neon signs. Krypton (Kr), on the other hand, has nothing to do with Superman's Kryptonite.

Radon (Rn) is radioactive. It is given off by certain forms of granite and other minerals. Recently, it has been found that some houses were built over rock which gives off enough radon to be dangerous.

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Houses over rock should be monitored at least once for radiation. See Chapter 8 for a discussion on the dangers of radon. All of the elemental gases are found in the right sector of the periodic table.

Place the noble gases into your periodic table. Develop a color key for the physical states of the elements, and lightly shade all the gases in your periodic table with one color and the liquids with another color.

VIIIA or 18
2 **He** Helium
10 **Ne** Neon
18 **Ar** Argon
36 **Kr** Krypton
54 **Xe** Xenon
86 **Rn** Radon

Exercise 4.4

4-9 Where are the nonreactive elements in the periodic table found?

4-10 Compounds of sodium chloride always have one atom of sodium per atom of chlorine.

- a. Predict the number of atoms of potassium that will react with one atom of chlorine in potassium chloride.
- b. Predict the number of atoms of fluorine that will react with one atom of sodium in sodium fluoride.

4-11 What radioactive gas is a noble element?

4-12 Which liquid element is a metal? A nonmetal?

4-13 a. Name two properties of the alkali metals.
b. Where are the alkali metals located in the periodic table?

4-14 Why are the alkali metals called metals even though they are soft?

4-15 In what portion of the periodic table are the elements almost all gases?

4-16 The properties of astatine can be predicted from the periodicity of the halogen properties and from the trends in its period. Use these to predict the following.

- a. Given that fluorine is pale yellow, chlorine yellow-green, and bromine red, and iodine a dark grey, what color is astatine?
- b. What is the physical state of astatine at room temperature?

4-17 Which of the halogens is necessary to prevent the disease, goiter?

4-18 What are the first and second most abundant elements in the Universe?

Activity 4.4 HALOGEN TRENDS

Purpose: to observe the similarities and differences in properties of a family of elements
Materials: sodium chloride (KLOR-eyed), sodium bromide (BROH-meyed), sodium iodide (EYE-oh-died), deionized water, test tube rack or beaker, stirring rod, 10 mL graduated cylinder, three 13 x 100 mm test tubes.
Procedure: Wear safety goggles. Wash hands thoroughly after completion of experiment.

Design an experiment to compare the solubilities of sodium chloride, sodium bromide, and sodium iodide in deionized water.

SOLUBILITY is the maximum quantity of the substance that can dissolve in a certain quantity of water at room temperature.

Your teacher will tell you how to obtain approval for your design before proceeding to carry out the activity.

Report Sheet:
Include your conclusions on the similarities and differences in solubility of the sodium halides.

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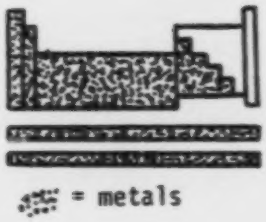
Section 4.5 OTHER ELEMENTS



A quick look has been taken at a metallic family, a nonmetallic family, and a nonreactive family, a total of seventeen elements.

Most of the 105 known elements are metals. They include many names that are probably familiar to you such as iron, cobalt, copper, nickel, lead, cadmium, zirconium, gold, silver, and platinum.

Certain metals are essential to the human body such as iron which is part of the structure of hemoglobin in the blood. Iron is also necessary to our mechanical and electronic civilization. Imagine, for example, what would happen to our civilization if all the iron we use turned to rust (a compound of iron and oxygen). Bridges and buildings would collapse, cars would fall apart, machines would crumble, and our modern society would not be able to function.

While metals are very useful and are essential to our civilization, some of them create real problems. Medical technology has revealed the dangers of the big three metal pollutants: mercury, lead, and cadmium. They are poisons which stay in our bodies when taken in because we cannot excrete them. Gradually, as more and more metal stays in the body, it causes severe damage to the nervous system and to internal organs. Mercury can be absorbed through the skin; it should never be handled without skin protection. The government has now made regulations to reduce the introduction of these metals into our environment by factories as waste.

Exercise 4.5

4-19 Why is it unsafe to handle mercury?

4-20 Which metallic element is essential to the hemoglobin in our blood?

Activity 4.5 ELEMENT OF THE WEEK

Purpose: to learn more about the elements.
Materials: library books
Procedure: Your whole class will become an abbreviated periodic table for this activity. Your teacher will assign family names to "columns" in your classroom and assign an element name to you based on your desk location. Prepare a five minute skit or mini-lecture about yourself as an element for presentation to your class.

CHAPTER 4 REVIEW

Vocabulary

Noble Gases
Helium
Periodicity
Luster
Brittle
Organization
Columns
Alkali Metals
Halogens
Periodic Table

Use each of the vocabulary words once to fill in the blanks shown in the sentences below.

1. When working with data, chemists find ______________________ an essential part of the scientific process.
2. One of the characteristics of metals is their ______________________ .
3. The ______________________ shows relationships between elements.
4. Elements which are ______________________ are classified as nonmetals.
5. The use of ______________________ instead of hydrogen in balloons makes them safer to use.
6. ______________________ are the most unreactive group of elements known.
7. Vertical ______________________ on the periodic table contain elements with similar properties.
8. All ______________________ react with water forming a flame.
9. Rows of elements across the periodic table show regular changes of properties described as ______________________ .
10. The ______________________ are reactive nonmetal elements.

Choose the vocabulary word below which best completes each blank in the sentences. Use each word only once.

conductivity malleability luster ductility

11. Only metals exhibit the special sheen called metallic ______________________.
12. The ______________________ of a substance can be tested with a hammer.
13. Copper metal can be drawn into long threads; this property of ______________________ makes this a good choice for home wiring.
14. The property of ______________________ can be tested with the aid of a source of electricity.

Which liquid element is a

nonmetal noble gas alkali metal metal
lanthanide halogen actinide

Select the term above about the periodic table which best fills the blanks below. Each term may be used only once.

15. To the left of the jagged line: ____________________
16. In the seventh period: ____________________
17. In the sixth period: ____________________
18. To the right of the jagged line: ____________________
19. Column VIIIA: ____________________
20. Column IA: ____________________
21. Column VIIA: ____________________

Applications

1. Use the data obtained in Activity 4.4 to predict the water solubility and physical appearance of sodium fluoride.

2. Why is radioactive strontium (Column 1) dangerous to your health? (Hint: calcium concentrates in human bones).

3. If you discovered a new highly unreactive, very heavy, monatomic gas trapped deep within the earth's core, to what column in the periodic table would you assign it?

4. Chlorine is often used to disinfect water. It is not practical to carry this element on a backpacking trip. Why do campers find iodine crystals a good substitute?

5. If one atom of aluminum requires exactly three atoms of chlorine to form the compound aluminum chloride, predict the number of
   a. fluorine atoms to one aluminum atom in aluminum fluoride, and
   b. fluorine atoms per one boron atom in boron fluoride.
   c. Explain your answers to a. and b. above.

6. Name four experimental tests which can be used to distinguish metals from nonmetals.

7. Discuss the importance of Mendeleyeff's work to the modern chemist.

8. Predict several properties of cesium (Column 1).

9. Name the two elements that are liquids at room temperature.

The following are multiple choice questions.

10. The name honored as inventor of the periodic table is
    a. Lavoisier; b. Newton; c. Galileo; d. Mendeleyeff.

11. The total number of known elements is closest to
    a. 70; b. 100; c. 150; d. 1000.

12. Periodicity in the periodic table refers to
    a. punctuation marks.
    b. gradual changes in properties which repeat regularly.
    c. arrangement in order of mass.
    d. length of time for a science class.

13. The first period has __________ elements in it.
    a. 2; b. 8; c. 18; d. 32

14. The period that is incomplete is the
    a. 1st; b. 4th; c. 5th; d. 7th.

15. The periods that contain transition elements are
    a. one, two, three.
    b. two, three, four.
    c. three, four, five.
    d. four, five, six.
    e. five, six, seven.

16. The most abundant element by number of atoms in the Universe is
    a. hydrogen; b. helium; c. oxygen; d. silicon.

17. Which of the following is a poisonous metal?
    a. mercury; b. bromine; c. iron; d. all of these

18. Which of the following could react explosively with water?
    a. cesium; b. oxygen; c. iodine; d. xenon

19. Which element would be the least likely to conduct electricity?
    a. cesium; b. chlorine; c. molybdenum (at. no. 42); d. cadmium (at. no. 48)

20. All of the halogens are radioactive.
    a. true; b. false

21. Which element is out of place in this series?
    a. Sb (at. no. 51); b. Sn; c. Si; d. C

22. The following is not characteristic of metals:
    a. good conductivity; b. shininess; c. brittleness; d. ductility.

23. Radioactive elements are usually located near the:
    a. top; b. bottom; c. left; d. right side of the periodic table.

24. I am an elemental gas, very corrosive, faint yellow in color. Who am I?
a. krypton; b. bromine; c. neon; d. fluorine

25. I am a dark colored halogen, the first solid in my family, I become an irritating gas very easily; I am diatomic. Who am I?
a. iodine; b. chlorine; c. xenon; d. bromine

26. The seventh period is made up of elements which are
a. unstable; b. radioactive; c. both a and b; d. neither a nor b.

27. Which one of the following groups of elements has members with the most similar properties?
a. S, P, Se; b. Na, Mg, Al; c. Cs, K, Rb; d. H, He, Li

28. Which of the following series of numbers are arranged by ordering them?
a. 2, 4, 6, 8; b. 2, 8, 6, 4; c. 3, 3, 3, 3; d. 29, 18, 47, 69

5

WHAT IS INSIDE AN ATOM?

Dalton thought that the atom was indivisible, that it was a hard sphere. Yet, about eighty years after Dalton theorized the existence of the atom, evidence began to accumulate that the atom is not solid but made up of distinct parts. The evidence for this began with the discovery of electrical charge. Electrical charge is all around us as the following activity will show.

*Activity 5.1 ELECTRICAL CHARGE IS ALL AROUND US

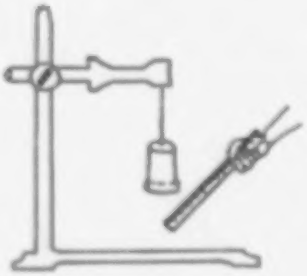
Purpose: to observe electrical effects in our everyday world.

Materials:

For Step 1: styrofoam cup, plastic ruler, ring stand and clamp, about 30 cm of thread, piece of tape, and a paper towel

For Step 2: small quantities of the following test materials: finely ground salt, sugar, pepper, small bits of paper, small bits of aluminum foil, small paper clip, and mashed corn flakes.

Procedure:



Step 1: STATIC CHARGE

1. Obtain the materials needed for Step 1.
2. Tape one end of the string to the outside of the cup at the middle of its bottom.
3. Set up the ringstand and utility clamp and hang the cup from it by the string so that it swings freely.
4. Bring the ruler near to the cup and then withdraw it. Observe. Gently touch the ruler to the cup and then withdraw it. Observe.
5. Rub the ruler vigorously between two pieces of paper towel.
6. Bring the ruler near to but not touching the styrofoam cup and observe. Try various ways of positioning the ruler near the cup.

7. Bring other objects near the cup and observe. Does your hand affect the cup?
8. Rub the ruler again and bring it to the cup and, this time, allow it to touch. Observe.

Step 2: CHARGING OTHER MATERIALS

Does the ruler affect other materials the way it does the styrofoam cup? To test this hypothesis, try the following.

1. Obtain small quantities of each of the seven test materials for Step 2.
2. Place a small quantity of each of the test materials in separate little piles on a sheet of paper.
3. Vigorously rub your ruler and then bring it horizontally slowly down to the salt until you can see an effect. Try to avoid getting any material on the ruler; clean it off with paper towel if you do. What happens?
4. Repeat this procedure with each of the other test materials. Which material seems to be most affected by the ruler?

Questions:

Q. 1 When the cup and unrubbed ruler were ready at the end of Step 1, No.4, was there any evidence that there were electrical charges present?

Q. 2 What did you observe during this entire activity that showed that electrical charges were present?

Q. 3 Did electrical charges always have the same effect? How do you know?

Q. 4 Do you think that electrical charges are present in everyday materials such as salt and pepper? What evidence supports your answer?

Conclusions: What did you learn about electrical charge in this activity?

Section 5.1 TYPES OF ELECTRICAL CHARGE

Electrical charge is all around us even without electric lines to bring it in. In Activity 5.1, no electric lines were plugged in to the wall socket; even so, electrical charge appeared on everyday objects. Yet, as recently as two hundred fifty years ago, the only electricity most people knew was lightning. Isn't it astonishing that something so fundamental, so much a part of every atom, was unsuspected and unknown for so long? What other knowledge lies in front of our eyes that we don't see?

Did you realize when you carried out Activity 5.1 that there are two different kinds of electrical charge? One kind of charge attracts the other kind to it but it *pushes away (REPELS)* its own kind.

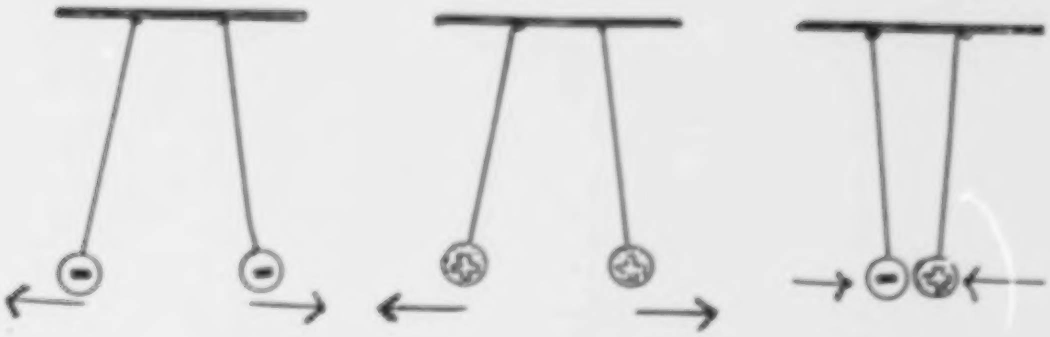
The two different kinds of electrical charges have been named ***POSITIVE*** and ***NEGATIVE***. These names just tell them apart from each other and have nothing to do with addition or subtraction.

When the charges on two objects are of the same kind (both positive or both negative), they are said to have *like charge*. From experiments such as Activity 5.1 above, scientists have found that

like charges repel;
unlike charges attract.

Attraction means that they move toward each other; *repulsion* means that they move away from each other:

both positively charged, repel
both negatively charged, repel
1 positive, 1 negative, attract



The negative charge comes from a particle within the atom called the **electron**. The positive charge comes from a particle within the atom called the **proton**.

The atom has parts inside; it is divisible! Dalton was wrong about atoms being solid spheres.

The positive charge on the proton is equal in quantity to the negative charge on the electron. Note that it is not the masses of the proton and electron that are equal; it is the quantities of electrical charge on each that are equal.

Exercise 5.1

5-1 For each of the following, select A or B below:
  A. they attract each other
  B. they repel each other

a. Two objects are both negative.
b. Two objects are both positive.
c. One of two objects is positive; the other is negative.
d. An electron approaches a proton.
e. An electron is near another electron.
f. An electron approaches an object of negative charge.
g. A proton approaches an object of negative charge.

Section 5.2 THE ELECTRICAL NATURE OF MATTER

5.2 A SCIENTIFIC MODELS

Where in the atom are the protons and electrons which carry charge? Although we are sure that atoms exist, there is no way to actually see inside them. We can only get clues from their behavior, from the way they affect other things, and from what we can find out by breaking them apart. From such evidence, we can form useful images of the interior of the atom. Such images are examples of scientific models.

A SCIENTIFIC MODEL is a visual or mathematical picture suggested by observation and/or experimental evidence.

Models make it easier for our minds to understand things; they picture them in familiar ways. The compounds that you constructed with toothpicks and spheres were models. *All models are imperfect.* They are only an attempt to picture what the evidence suggest. They omit unimportant details. Models often become outdated as scientists gather new information.

Physical models may be drawings, paintings in full color, or three-dimensional constructions. Models can instead be most useful as word descriptions or mathematical descriptions. They may range all the way from those which omit only a little of the visible physical appearance to those that represent things we can never see. All models are simplifications which are used to help us understand the reality.

5.2 B MODEL OF AN ATOM

Scientists have developed a useful model of the atom to show where the protons and electrons are. This model pictures the atom with *a very tiny, very dense center called the* ***NUCLEUS.***

The nucleus appears to be made up of two different kinds of particles. One kind is the proton which we have met as a carrier of positive charge. The other kind is a particle called the neutron (discovered in 1932) which has about the same mass as the proton but has no charge. (Thus, the nucleus is positively charged.)

The space in the atom surrounding the nucleus is much much bigger (about 100 000 times bigger) than the nucleus itself. The region outside of the nucleus contains all of the electrons. Thus, it contains all of the negative charge.

The size of the nucleus compared to the size of an atom is like the size of the period at the end of this sentence compared to the size of a card table. Evidently, most of the space in the atom is taken up by the electrons.

The proton and the neutron have masses very close to each other. Each has a much much greater mass than an electron has (over eighteen hundred times as much).

**Q. 1 Where is most of the mass of the atom, in the nucleus or in the space outside of the nucleus?

Table 5.1 summarizes this information about the particles in the atom. A charge of -1 is assigned to an electron and +1 to a proton. The charges are equal in quantity but opposite in effect.

Table 5.1 Subatomic Particles

Particle	Symbol	Charge	Location	Mass
proton	p	+1	nucleus	very massive compared to electron
neutron	n	0	nucleus	almost same as proton
electron	e	−1	outside nucleus	very very small

We have pictured atoms with protons and neutrons packed into nuclei but we really do not know if this is so. Our image is only a useful model. Maybe the nuclei are made up of other particles which convert to protons and neutrons when outside energy reaches them. Today's nuclear scientists are using an advanced model of the atom in which the nucleus is made up of even more fundamental particles than protons and neutrons.*

Exercise 5.2

5-2 How does a scientific model differ from a clothing model?

(Exercise 5.2 is continued on the next page)

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*Scientists who have shattered the "mystery box" of the nucleus have obtained over 100 different kinds of fragments. Many scientists believe that certain fundamental particles called quarks and leptons found among these fragments are truly the basic units of the universe. The knowledge will help us to better understand our universe and, perhaps, to even answer how our universe started.

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5-3 a. Why are all scientific models imperfect?
  b. Give an example of a model which organizes information.
  c. Can more than one model of something be developed?
5-4 Why are models important?
5-5 What effect do neutrons have on the charge of an atom?
5-6 Where in the atom are the electrons located?
5-7 Which has more mass, an electron or a proton?
5-8 Which has the larger quantity of charge, an electron or a proton?
5-9 Compare the mass of a neutron to a proton.
5-10 What is the nucleus of the atom?

Answer to Question
Q. 1 Most of the mass of the atom is deep inside, in the tiny nucleus.

---

*Activity 5.2 THE MYSTERY BOXES

Purpose: to make a model of the inside of a box without opening it
Materials: three Mystery Boxes
Procedure:

This is a simulation of one of the processes which scientists have used to develop an idea of the structure of the atom. One way to find out what's in an atom is by shattering it. Then, the parts are examined. Unfortunately, each time that an atom is shattered in a different way, different parts are obtained. It's like Humpty-Dumpty; they can't put it back together again, so scientists really don't know just what it is like deep inside an atom.

Another way to learn a great deal about an atom is to observe the whole atom as best as possible without shattering it. You will simulate this process using a sealed box as a model of an atom. You will obtain data about the contents of three sealed boxes (atoms of three different elements).

Observe the whole box. You can gently shake it, tilt it, listen to motion inside, or do any other kind of physical thing that doesn't damage it. In that way, you can make some hypotheses about the contents of the box. You may be able to say how many objects are in the box, whether they are all hard or soft, whether any is round or square or some other shape, whether one or more is heavy, and so on.

The class will be divided into three teams. Each team will receive an identical set of three boxes. After everyone in the team has handled one box, the team must agree together on what is in it. When you have agreed on what you think is in it, have someone on your team write it down. All of you on the team should sign this report. Do this for each box.

When the class has completed its data, there will be a class discussion on what is in the boxes.

Section 5.3 ATOMIC NUMBER

The number of protons in the nucleus of an atom is called its
ATOMIC NUMBER.

Every element has a different atomic number. Hydrogen, the lightest of all elements, has one proton in its nucleus; its atomic number is 1. Helium, the next element in order of mass, has two protons and an atomic number of 2. Lithium has three protons and beryllium has four and so on. As the atomic number increases, the atomic mass increases for most but not all of the elements.

The modern periodic table has the elements in the order of their atomic numbers, not in the order of mass as Mendeleyeff did. The atomic number is a better criterion for ordering the elements than the atomic mass because then the properties of the element line up better, too. In the periodic table, the atomic number is the integer in each box. Examine the periodic table to see how the elements are lined up in order of atomic number.

**Q. 1 How many elements are there for each atomic number?

An element can be identified by its name or by its symbol or by its atomic number. All are unique to that element only. For example, you can call the element, krypton

by its name, krypton, or
by its atomic number, 36, or
by its symbol, Kr.

If one or more protons in the nucleus are shattered as in an atomic reactor, then the atomic number of the element changes and it is no longer the same element. Only a nuclear reaction, such as in an atomic reactor, can change the identity of an element.

During a chemical reaction, the number of protons never changes; therefore, the identity of each atom never changes during a chemical reaction. Chemical reactions involve only changes in chemical partners, not changes inside the nucleus.

In your periodic table, fill in the atomic numbers for all the elements whose symbols you have put on it.

Exercise 5.3

5-11 With the help of a periodic table, find the number of protons in the nucleus of

a. carbon.
b. phosphorus.
c. argon.
d. calcium.
e. antimony (Sb, see period 5).
f. silver (Ag, see period 5).
g. gold (Au, one period below silver).

5-12 Do you think that an element will be discovered some day which fits in between aluminum (atomic number 13) and silicon (atomic number 14)? Why?

5-13 Find two pairs of elements in the periodic table which are not ordered by atomic mass.

Answer to Q

Q.1 For each atomic number, there is only one element.

Section 5.4 ATOMIC VOLUME AND MASS

Atoms are extremely small. There may be a trillion trillion atoms in your fingernail alone. Their masses are correspondingly small. It is not convenient to use grams or even milligrams as a unit of measurement for atomic mass.

Just as there is a standard length unit in the common system of measurement based on the human foot, there is a standard atomic mass unit used by scientists which is based on a real atom. The atomic mass base unit comes from the carbon atom with six protons and six neutrons in it, called the carbon-12 atom. The carbon-12 atom has a mass of exactly 12 atomic mass units (abbreviated as 12 amu or 12 *u*).*

All other atomic masses are compared to the carbon-12 atom. For example, oxygen has a mass about 16/12 (or 4/3) as much as that of carbon so its atomic mass is about 16 amu. The mass of a hydrogen atom is about 1/12 as much as that of the carbon atom so it has a mass of about 1 amu.

In the periodic table, the atomic masses in atomic mass units are the numbers shown to one or more decimal places. For example, nitrogen, (atomic number 7) has 14.0 *u* per atom. Neon has 20.2 *u* per atom.

---

*One amu is extremely small, 0.000 000 000 000 000 000 000 002 g.

The atomic masses given in this book are rounded to two decimal places in the periodic table (see page 47). As of now, some of them are known to five decimal places and one is known to six decimal places.

Exercise 5.4

5-14 From your periodic table, find the mass in amu of an atom of
  a. cobalt (at. no. 27)
  b hafnium (at. no. 72)
  c. mercury (at. no. 80)
  d. uranium (at. no. 92)

5-15 State whether each of the following is true or false.
  a. A raindrop has millions of atoms in it.
  b. The volume of a hundred nuclei is most probably not as big as the volume of one atom.

Section 5.5 ISOTOPES

The model of the atom used so far can explain something else about the atom that Dalton didn't know about. Dalton believed that all atoms of an element are identical but this is not so. The atoms of an element all have the same number of protons in the nucleus but they may differ in the number of neutrons. Since it is the number of protons which determines the identity of the atom, atoms can have the same identity and still differ in the number of neutrons.

Scientists believe that neutrons act as a sort of nuclear glue. Without the neutrons, the protons would repel each other right out of the nucleus.

Since only the protons determine the identity of an element, a carbon atom with 6 neutrons and a carbon atom with 8 neutrons are both carbon. They both have 6 protons and that's what counts. Both kinds of carbon atoms exist in nature as well as carbon with 7 neutrons.

Atoms of the same element that contain different numbers of neutrons are called ***ISOTOPES*** *of each other.*

Every element has two or more isotopes. The higher the atomic number, the more isotopes an element tends to have.

**Q. 1 Do two isotopes of the same element have the same atomic mass?

Elements in their natural state (as found in the earth, air, or water) are always a mixture of two or more isotopes.

Exercise 5.5

5-16 Neutrons have been said to act as a nuclear glue. Why does the nucleus need a nuclear glue?

5-17 Do isotopes of the same element have the same chemical properties? Explain.

5-18 Which of the following pairs is (are) made up of two atoms which are isotopes of each other?

.	number of protons	number of neutrons
a.	7 7	7 8
b.	9 10	10 9
c.	9 9	10 9
d.	10 9	10 9

Answer to Q
Q. 1 no

Section 5.6 NEUTRAL, POSITIVE, NEGATIVE

Most of the volume of the atom is occupied by the electrons. They are completely outside of the tiny nucleus. The positive protons in the nucleus attract the negative electrons around the nucleus and help to keep the electrons from repelling each other out of the atom.

When an atom has an equal number of positive and negative charges,
the atom acts from a distance as if it has no charge at all;
*it is said to be **NEUTRAL**.*

Recall that the quantity of the charge on one electron is equal and opposite to the quantity on one proton so an atom is neutral when it has an equal number of protons and electrons.

Electrons can be removed from or added to an atom. In Activity 5.1, you rubbed electrons off one material and onto another. In all cases, it is the ELECTRONS THAT FLOW from one object to the other. Protons are not free to move from deep inside the atom.

When an atom gains an electron, it has more electrons than protons so it is negative.

An atom that loses one or more electrons has more protons than electrons; it is positive.

Exercise 5.6

5-19 Hydrogen has one proton. How many electrons does a neutral atom of hydrogen have?

5-20 How many electrons does a neutral atom of fluorine have? (Hint: find the atomic number of fluorine from the periodic table.)

5-21 How many electrons does a neutral atom of each of the following have?
  a. titanium (atomic number 22)
  b. sodium
  c. krypton
  d. iodine

5-22 What kind of charge does a mass have when it
  a. has more electrons than protons?
  b. has only protons present?
  c. has an equal number of protons and electrons?
  d. is neutral and then has additional electrons added to it?
  e. has more protons than electrons?
  f. is an atom from which electrons have been removed?

5-23 A neutral atom of copper has 29 electrons. How many protons does it have?

5-24 How many electrons are needed to balance the charge on an atom of manganese with 25 protons and 29 neutrons?

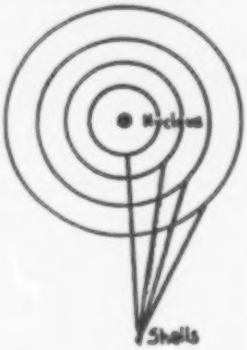
5-25 State whether each of the following is neutral, positive, or negative.
  a. a fluorine atom with 9 electrons and 9 protons
  b. a fluorine atom with ten electrons and nine protons
  c. a potassium atom with 19 electrons and 19 protons
  d. a potassium atom with 18 electrons and 19 protons

Section 5.7 MODIFIED BOHR MODEL

A great step forward in picturing the inside of the atom came in 1913 when the Danish scientist, Niels Bohr (pronounced Bawr), developed a mathematical model of the hydrogen atom. From Bohr's mathematical model, a visual model has been worked out for all the elements.

In this model, the electrons continuously move in orbits around the positively charged nucleus somewhat like the way planets move around the sun.

Groups of orbits cluster at different distances from the nucleus. These clusters are called SHELLS or ENERGY LEVELS.



The shells become bigger the further they are from the nucleus. As a result, each shell going outward can hold more electrons up to some maximum number.

The diagram at the right pictures this model. This picture of the atom shows the electron **CONFIGURATION** (arrangement).

The electrons on each atom fill the energy levels in order from the inside out. When an atom has too many electrons for them all to fit into the innermost shell, the extras go into the next shell outside of it, and then into the one outside of that, and so on. The element with the highest atomic number known, No. 105, has seven electron shells.

Newer models of the atom exist which predict some actual behaviors of elements that the Bohr model does not. The quantum (KWANT-um) mechanical model of the atom is a complex statistical mathematical model which describes electron locations in terms of the probabilities that they can be found in certain regions.

Exercise 5.7

5-26 In the Bohr model, are all the electrons at the same distance from the nucleus?

5-27 The innermost shell of electrons can only hold a maximum of two electrons. Lithium has three electrons. How are its electrons arranged?

5-28 What is the maximum number of shells of electrons now known for an element?

5-29 How does the number of electrons that can fit into the fifth energy level of an atom (counting from the nucleus outward) compare to the number in the sixth energy level?

Section 5.8 THE BOHR MODEL AND THE PERIODIC TABLE

5.8 A THE PERIODS

The Bohr model is a theoretical one. Mendeleyeff's periodic table is based on the actual properties of the elements. Can the theoretical model explain the one based on real data? Are the properties of the elements based, at least in part, on electron layouts? Indeed, the Bohr model and the periodic table interface splendidly!

First, how does the Bohr model explain the periods?

The seven shells of the Bohr model correspond to the seven periods (or rows) of the periodic table. The number of the period in which an element is found in the periodic table is the same as the total number of Bohr shells for that element.

Exercise 5.8 A

5-30 An element has two energy levels in which electrons can be found. In what period of the table is this element located?

5.8 B ELECTRON CONFIGURATIONS WITHIN THE PERIODS

The first shell of electrons in any atom can hold only two electrons at most. Hydrogen (atomic number one) has one electron and helium (atomic number two) has two electrons. All of the other elements in the periodic table have more than two electrons. Elements in Period One can have only one shell. Hence, Period One holds only hydrogen and helium.

The second shell, moving outward, can hold a maximum of eight electrons. As a result, there are eight different elements in Period Two with, successively, three to ten electrons in all; two electrons are in the first shell (or energy level) and the remainder in the second shell.

The third shell can hold more electrons, and so on.

A diagram of this is shows for the Bohr model of the first eighteen elements in the periodic table. Each circle in the diagram represents an energy level in which the electrons are moving. The number of dots represents the number of electrons in that energy level. The total number of electrons for each atom equals its atomic number. Check a few atoms in the diagram to be sure for yourself that the number of electrons equals the atomic number.

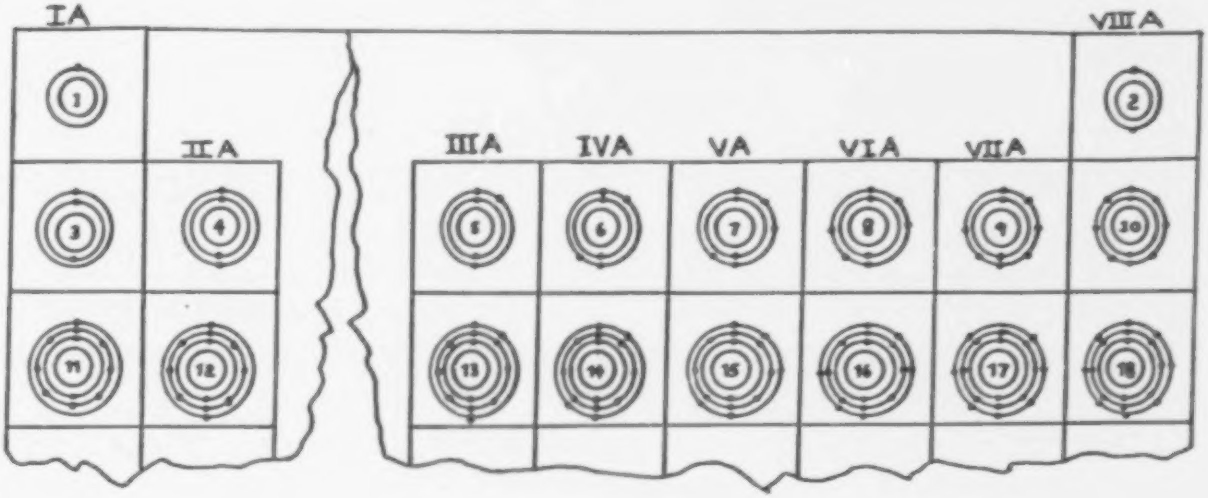


Figure 5.1 Electron Configurations in the First Three Periods

Exercise 5.8 B

5-31 An element is located in Period Five.

a. How many energy levels does its electrons occupy?

b. Does it have more or less electrons than an element with four energy levels?

5.8 C THE FAMILIES

Next, how does the Bohr electron model of the atom explain the similar properties among the members of each column?

**Q. 1 According to Figure 5.1, how many electrons are in the outermost shell of all the elements in column 1A?

**Q. 2 How many electrons are in the outermost shell of all the elements in column VA?

**Q. 3 How many electrons are in the outermost shell of all the elements in Column VIIA?

The Bohr theory explains the columns of the periodic table! Each column differs from the next one in the number of OUTERMOST electrons.

All of the elements in any one column of the periodic table have the same number of outermost electrons. Although we have not covered the transition elements, lanthanides, and actinides, it is possible to predict electron arrangements of each of the elements from its position in the periodic table.

We conclude that the electron configuration of the elements explains the layout of the periodic table. The periodic table didn't just happen to work out. Mother Nature set up the rules for arranging electrons, and their configurations explain much of the behavior of the elements.

Exercise 5.8 C

5-32 Sketch the electron configurations for hydrogen, lithium, and sodium using diagrams like those in Figure 5.1.

5-33 What is alike in the electron configurations of all the elements in the second period?

5-34 What is alike in the electron configurations of all the elements in column VIIA?

Answers to Q's

Q. 1 1 electron; Q. 2 5 electrons; Q. 3 7 electrons

* * *

Chapter Five Review

Vocabulary

Neutral
Positive
Neutron
Proton
Electron

Configuration
Negative
Isotopes
Atomic Number

Choose the term from the list above which best completes the blanks below. Use each word only once.

1. By what name do we refer to atoms with the same atomic number but different atomic masses? ________________________.
2. The charge on a proton is ________________________ .
3. What term is used to describe the distribution and number of electrons of an atom?

   ________________________ .
4. The charge on an electron is ________________________ .
5. A(n) ________________________ object acts as if it has no charge.
6. What fundamental particle is located outside the nucleus?

   ____
7. Which vocabulary term gives the number of protons in an atom?

   ____
8. Which fundamental particle is charged and contributes most of the mass of an atom?

   ____
9. Which particle in an atom has no charge? ________________________

Applications

Choose the type of model from the list below which best fits the phrase in Questions 1-4.

Clothes Model
Bohr Model
Quantum Mechanical Model
Scientific Model

1. any model based on experimental evidence
2. window display
3. electrons orbiting around nucleus
4. complex analysis which often requires the aid of a computer

Select the best choice to complete the statements from 5-23.

5. Two objects hanging near to each other are both charged positively. They
   a. do not affect each other.
   b. are attracted toward each other.
   c. repel each other.

6. Two charged objects attract each other.
   a. They are both positive.
   b. They are both negative.
   c. One is positive and one is negative.
   d. Both a and b are correct.

7. The identity of an atom is determined by its number of
   a. electrons; b. protons; c. neutrons; d. isotopes

8. Isotopes of neutral atoms contain the same number of
   a. neutrons; b. electrons; c. protons;
   d. a and b are correct; e. b and c are correct

9. Choose the FALSE statement about a neutral atom of lithium. (Lithium has an atomic mass of 7 and an atomic number of 3.)
   a. It has 3 protons. c. It has no neutrons.
   b. It has 3 electrons. d. It is electrically balanced.

10. A neutral atom of oxygen has two electrons added to it. It is now
    a. positive; b. negative; c. neutral

11. Scientific models are always imperfect.
    a. true; b. false

12. The mass of an atom is
    a. the sum of the protons, electrons, and neutrons in the atom.
    b. smeared equally throughout the atom.
    c. concentrated in the nucleus.
    d. impossible to determine.

13. Most of the volume of an atom is occupied by
    a. neutrons.
    b. protons.
    c. electrons.

14. The modern periodic table is ordered according to
    a. the average masses of the elements.
    b. the number of protons of the elements.
    c. the number of neutrons of the elements.
    d. the total number of protons and neutrons of the elements.

15. The identity of an element could be changed if ______________________ could be added or removed.
    a. electrons
    b. protons
    c. neutrons

16. Two electrons are removed from an atom of oxygen. The atom is now
    a. positive
    b. negative
    c. neutral
    d. changed to an atom of a different element

17. All the atoms of carbon have the same
    a. atomic mass
    b. number of protons
    c. number of neutrons
    d. number of protons plus neutrons

18. Elements located in the same column of the periodic table have the same number of
    a. shells of electrons
    b. outermost electrons
    c. protons
    d. electrons

19. Sodium (atomic number 11) has one outermost electron. Magnesium (atomic number 12) has two outermost electrons. How many outermost electrons does potassium (atomic number 19) have?
    a. 1; b. 2; c. 4; d. 7; e. 8

20. The quantum mechanical model of the atom
    a. is the same as the Bohr model.
    b. is based on complex mathematics.
    c. both of the above are correct.

21. Diagrams of Bohr orbits are
    a. models.
    b. exact pictures of electrons.
    c. pictures which show the planets around the sun.
    d. statistical representations.

22. The maximum number of electrons that can fit into an outermost energy level is ______________________ the maximum that can fit into the innermost level.
    a. greater than; b. the same as; c. less than

23. The number of Bohr energy levels for a neutral atom determines its
    a. period; b. group; c. atomic number;
    d. number of outermost electrons.

The following questions require short answers. Use your periodic table where needed.

24. How is it possible for scientists to propose a model of the internal structure of the atom when they cannot actually see inside the atom?

25. Name the element which has an atom containing 13 electrons, 13 protons, and 14 neutrons.

26. From the diagram of electron configurations, it can be seen that the number of outermost electrons in the configurations of the noble gases, except for helium, is

______________________________ .

27. How many electrons are in a neutral atom of each element listed below (hint: look in the first 3 periods).

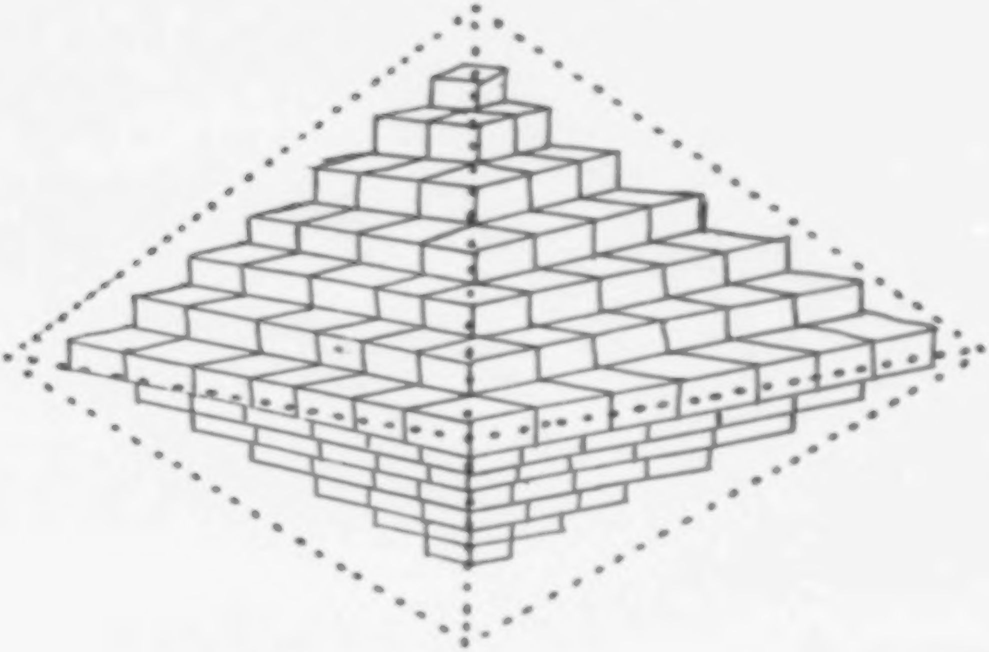
a. magnesium
b. boron
c. fluorine

28. What is the total number of shells of every element in the fifth period?

29. What is the isotope upon which all the other atomic masses are based? How many protons, neutrons, and electrons does it have?

6

BONDING



Section 6.1 TWO DIFFERENT KINDS OF BONDS

Sugar and salt are very different compounds in many ways besides taste. Sugar melts at a low temperature; salt melts at a very high temperature. Sugar chars on heating; when salt is heated, the crystals bounce around but they don't burn.

The differences in the properties of salt and sugar arise from their internal structures. Salt and sugar are different because the linkages or bonds between their atoms are of two very different types.

Each link that holds two atoms together is called a
CHEMICAL BOND.

The process of forming stable links between atoms is called
CHEMICAL BONDING.

The atoms in salt are bonded ionically (eye-ON-ik-uh-lee) whereas those in sugar are covalent (koh-VAY-lent) bonds. These two different types of bonds, ionic and covalent, will be discussed in the next sections.

When any two atoms approach each other in the process of bonding, it is their outermost electrons which are exposed to each other. Bonding involves electrons, particularly those outermost ones. Protons, on the other hand, are not part of the bonds formed between atoms. Our model of the atom has a tiny, positive nucleus buried deep inside the surrounding electrons. The protons in the nucleus are too far inside their protective cloud of electrons to be a direct part of chemical bonds with other atoms.

Exercise 6.1

6-1 What is a chemical bond?
6-2 Which of the three particles found in an atom is directly involved in bonding?
6-3 Why doesn't an atom gain or lose protons when bonding?

Section 6.2 IONS

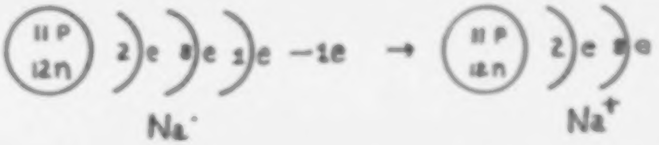
6.2 A POSITIVE AND NEGATIVE IONS

It is possible for some atoms to lose electrons and for other atoms to gain them in order to become more stable.

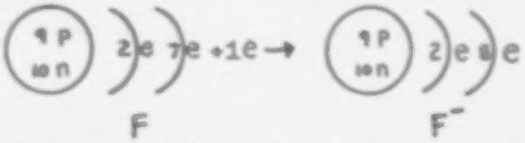
Particles which have gained or lost electrons are called
IONS *(EYE-onnz).*

When an atom loses one or more electrons, it then contains more positive charge than negative charge. Hence, atoms which lose electrons are positively charged.

For example, sodium has 11 protons, 12 neutrons, and 11 electrons. When a sodium atom loses one electron, it forms an ion with a charge of 1+. (The charge on 10 protons is neutralized by 10 electrons leaving one proton with a charge of 1+ not neutralized).



Fluorine is an element which can gain one electron. Fluorine has 9 electrons and 9 protons. When fluorine forms an ion with 10 electrons, it has one more electron than it has protons so its ion has a charge of 1−.



**Q.1 If a particle is positively charged, does it have more protons than electrons or more electrons than protons?

**Q.2 To make a neutral particle become negatively charged, should electrons be added to or removed from it?

**Q.3 To make a neutral particle become positively charged, should electrons be added to or removed from it?

As a general rule,

METALS FORM IONS BY LOSING ELECTRONS;

WHEN NONMETALS FORM IONS, THEY DO SO BY GAINING ELECTRONS.

Accordingly, all of the elements to the left of the jagged line in the periodic table tend to form ions by losing electrons. When the nonmetals to the right of the jagged line form ions, they do so by gaining electrons.

Exercise 6.2 A

6-4 Identify each of the following as a positive ion, negative ion, or neutral atom.
- a. a barium atom which has lost two electrons
- b. a calcium atom with 20 electrons and 20 protons
- c. a calcium atom with 18 electrons and 20 protons
- d. a chlorine atom which has gained one electron

6-5 Identify each of the following as a positive ion, negative ion, or neutral atom.
- a. an atom with 54 electrons and 53 protons
- b. a lithium atom (atomic number 3) with two electrons
- c. an oxygen atom (atomic number 8) with ten electrons
- d. a helium atom with two electrons
- e. a hydrogen atom with no electrons

6-6 Based on the periodic table, which of the following elements tend to form positive ions? (The number in parentheses after the name of the element below is its atomic number.)

a. potassium (19); b. iron (26); c. bromine (35); d. xenon (54).

Answers to Q's

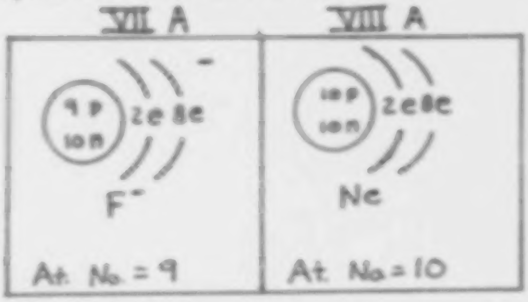
Q. 1 A positively charged particle has more protons than electrons.

Q. 2 To become negatively charged, a particle needs more electrons than protons. Electrons must be added to give it a negative charge.

Q. 3 To become positively charged, an atom must lose one or more electrons so that it has more protons than electrons.

Optional: 6.2 B WHY METALS TEND TO LOSE ELECTRONS AND NONMETALS TEND TO GAIN THEM

The theory of electron configuration provides an explanation for the tendency of metals to lose electrons and nonmetals to gain them. The explanation arises from the fact that the noble gases are unreactive. The electron arrangements of the noble gases must, therefore, be stable configurations. All metals are elements with one, two or three outermost electrons. When metals lose their outermost electrons (one, two, or three depending on whether they are in Column IA, IIA, or IIIA), they are left with the electron configuration of the nearest noble gas preceding them in the periodic table.



The nonmetals which can gain electrons have five, six, or seven electrons. They have too many outer electrons to give any up but they can instead gain some. The nonmetals can gain one, two, or three electrons to have eight outermost electrons. When they have eight outer electrons, they have the same electron configuration as the noble gas which directly follows them in the periodic table. Noble gases are stable with their outer eight electrons (octets). Hence, when a nonmetal completes the octet by gaining electrons, it has the same electron configuration as the nearest noble gas and forms a stable ion.

Metals	Nonmetals
Have 1, 2, or 3 outer electrons	Have 5, 6, or 7 outer electrons
Lose 1, 2, or 3 outer electrons	Gain 3, 2, or 1 outer electrons
Form positive ions	Form negative ions

Instead of defining metals in terms of their physical properties, metals can be defined in terms of their tendency to lose electrons.

By knowing what kind of ion an element forms under the given conditions and how many electrons are involved, chemists gain great power in predicting reactions.

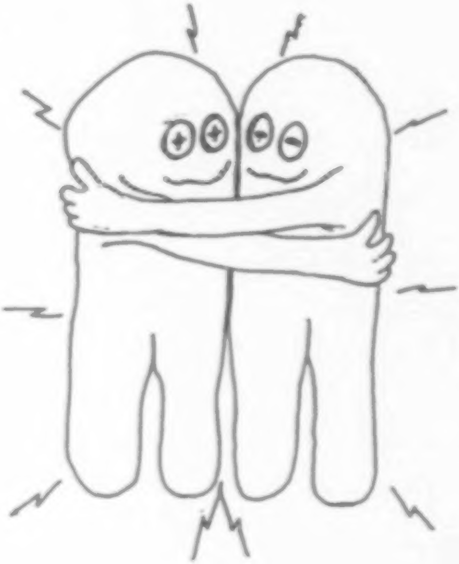
Exercise 6.2 B

6-7 Identify each of the following as a property of a metal or nonmetal.

a. can form an ion with more electrons than protons .
b. easily loses electrons
c. tends to form negative ions
d. reacts to gain an electron
e. forms an ion with the electron configuration of a noble gas PRECEDING it
f. forms an ion with the electron configuration of the noble gas FOLLOWING it

Section 6.3 IONIC BONDING

6.3 A THE IONIC BOND



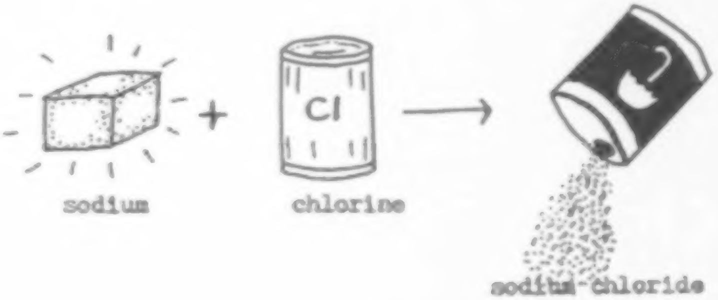
Ions of opposite charge attract each other. The attraction acts as a strong force to bind ions together.

Bonds between positive and negative ions are called ***IONIC BONDS.***

The metallic ions are the positive ones. The nonmetallic ions are the negative ions. They form bonds because of the attractive electrical forces between their opposite charges. These bonds hold ionic compounds together.

The total negative charge in ionic compounds equals the total positive charge so the ionic compounds are neutral.

The atoms of an element can be very different from the ions of the same element. For example, sodium and chlorine react to form table salt, sodium chloride, an ionic compound. Elemental sodium is a soft metal (in Column IA) which is so reactive that it combines with air or with water. Chlorine (Column VIIA) is a poisonous pale green gas. Sodium and chlorine react dramatically with a burst of orange flame to produce a white powder.



The powder is table salt. Its ions are colorless, stable, and nonpoisonous. It is clearly different from the neutral atoms of the elements that make it up.

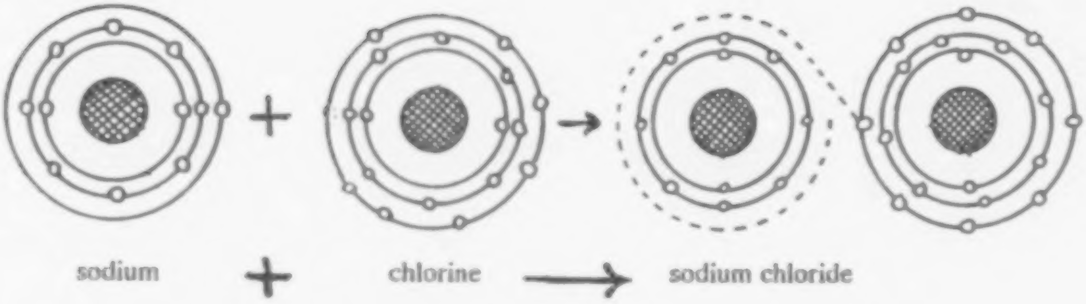


Figure 1 Reaction of Sodium and Chlorine

As a result of the reaction, each sodium atom loses one electron; the sodium ion formed has a charge of +1. Each chlorine atom gains one electron during the reaction to form the chloride ion with a charge of −1.

The sodium ion is written as Na^+. The + stands for a charge of 1+; customarily, the "1" is omitted. The chloride ion is written as Cl^-. Its "1" is also omitted. Notice that when the charge is shown, it is as a *SUPERSCRIPT* (raised). An aluminum ion which loses three electrons is written as Al^{3+}. An oxygen atom which gains two electrons is written as O^{2-}.

Positive sodium ions electrically attract the negative chloride ions to form strong bonds between them. The compound formed, sodium chloride, is quite stable.

Exercise 6.3 A

6-8 What is an ionic bond?

6-9 What forms the ionic bond in sodium chloride?

6-10 Write the ionic symbol for
  a. an atom of gallium, Ga, which has lost three electrons.
  b. an atom of sulfur which has gained two electrons.

Optional 6.3 B BINARY COMPOUNDS

*Compounds made up of only two elements are called **BINARY COMPOUNDS**.*

When naming a binary compound formed by a metallic ion and a nonmetallic negative ion,
(1) the metallic ion keeps the name of its element;
(2) the negative ion changes its name by replacing the last part of the element's name with *ide*.

Examples are sodium chloride, potassium nitride, aluminum oxide, and calcium sulfide.

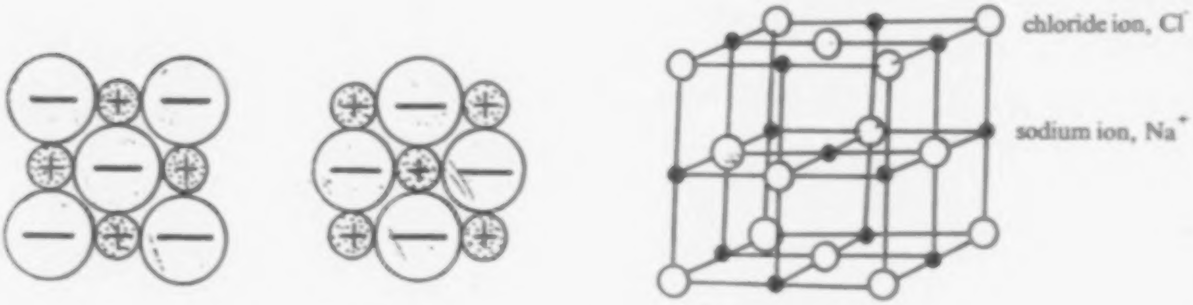
Exercise 6.3 B

6-11 What is the name of the binary compound formed by
  a. sodium and bromine
  b. calcium and oxygen
  c. aluminum and sulfur
  d. magnesium and nitrogen?

Optional 6.3 C IONIC CRYSTALS

Sodium chloride crystals (table salt) are made up of equal numbers of positive sodium ions and negative chloride ions. Since the numbers of positive and negative charges are equal, the compound is neutral. You don't get a shock when you touch table salt even though it is made up of charged particles.

Each of the positive ions in an ionic solid attracts an envelope of negative ions around it. Each negative ion in an envelope attracts its own envelope of positive ions. Networks of ions form. The arrangement creates the crystalline shape of the solid.



First layer Second layer Ball and stick model

Sodium Chloride Crystalline Arrangement

The ionic bonds between the billions and billions of oppositely charged particles hold the crystal together. Overall, there is one ion of sodium per each one chloride ion.

The regular arrangement of the ions forms the regular planes that make up the beautiful crystals we see. Ionic compounds, almost without exception, are solids. You can assume that substances which are liquids or gases do not have ionic bonds (but not all substances which are solid have ionic bonds).

Exercise 6.3 C

6-12 How are positive ions kept from repelling other positive ions in an ionic crystal?

6-13 A compound is a gas at room temperature. Is it an ionic compound?

6-14 How can a compound be made up of positive and negative ions and still be neutral?

6-15 How many chloride ions are there per sodium ion in sodium chloride?

Optional: Section 6.4 OXIDATION-REDUCTION

Elements can lose electrons while other elements gain them during a chemical or electrochemical reaction. *OXIDATION is the process by which electrons are lost while REDUCTION is the gain of electrons.* Oxidation and reduction always take place together; one element loses electrons while another gains them. Elements which lose electrons are said to be **oxidized** while those that gain the electrons are **reduced**.

Fig. 1 shows an example of a reaction in which sodium is oxidized and chlorine is reduced.

The class of reactions in which oxidation and reduction take place is large and includes burning, battery reactions, bleaching, rusting, corroding, digesting, photosynthesis, and many others.

Once ions have formed, they can undergo many different types of reactions as ions without undergoing any further oxidation-reduction or, under the right circumstances, they can be reduced or oxidized.

Exercise 6.4

6-16 Calcium (at. no. 20) reacts with an acid to form an ionic compound.
  a. Is the calcium oxidized or reduced?
  b. Calcium loses two electrons to form an ion. What is the charge on the calcium ion after the reaction?
  c. Will calcium ions be more likely to bond to sodium ions or to chloride ions?

Section 6.5 COVALENT BONDING

Getting back to sugar, does that mean that sugar particles are split up into ions? No, no, no. There is no evidence to suggest that sugar is made up of ions. In fact, all the evidence shows that each sugar particle contains carbon atoms linked to at least one other carbon atom. Since they are identical, how can one carbon atom pull an electron away from another one?

6.5 A COVALENT OCTETS

We have seen that nonmetals form ionic bonds with metals, but nonmetals can also bond to other nonmetals. The atoms do not form ions in such compounds. All the evidence shows that nonmetals form bonds to each other in which they share two electrons, one from each atom.

Nonmetals are believed to share electrons to form the same stable outer octet of electrons as do the noble gases. In this way, the nonmetals can become stable. To see this, let us look at a particle of chlorine gas at room temperature. Chlorine gas is made up of particles each consisting of two atoms bonded together. See Figure 2 below. Each chlorine atom has seven outer electrons. Each lacks only one electron to form a stable electron octet (as in the noble gas, argon). By sharing the electrons in a bond between them, each chlorine atom has an outer octet (count the outer electrons).

In Figure 2 following, each big outside circle shows the outer electrons of one chlorine atom. Where the circles overlap, the electrons are shared by both atoms. In the overlap, one electron comes from one chlorine atom and one from the other. Now, there are eight electrons in each big outside circle of the diagram.

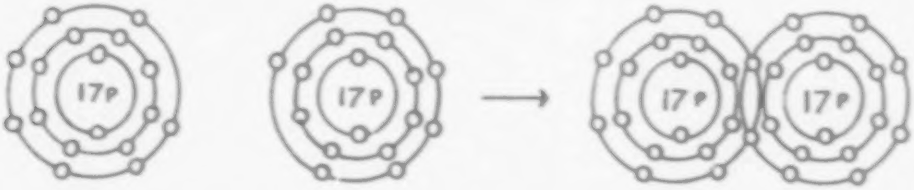


Figure 2 Electron Configuration of the Elemental Chlorine Particle

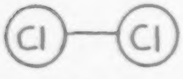
The shared electron pairs hold nonmetallic atoms together and give them stability.

Each pair of shared electrons forms a **COVALENT** *(koh-VAY-lent)* **bond.**

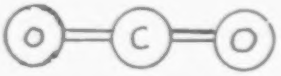
The two nonmetal atoms do not have to be the same element. Different nonmetal atoms can bond covalently, too.

Elements can usually share their outermost electrons only. With the exception of hydrogen, elements which share outer electrons end up with a total of eight outer electrons. Once they have the outer octet, they tend to be stable.

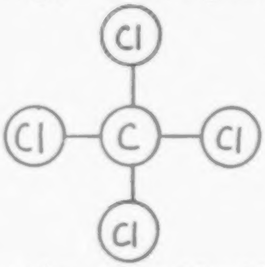
A nonmetal atom may form more than one covalent bond to another atom, or may form covalent bonds to more than one atom. Below are diagrams of some particles; each electron pair bond is shown as a straight line.



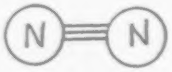
chlorine gas



carbon dioxide



carbon tetrachloride



nitrogen gas

1. Nonmetals can bond to metals when both are ions.
2. Nonmetals can bond covalently to other nonmetals.

Exercise 6.5 A

6-17 What is a covalent bond?

6-18 When a metal bonds to a nonmetal,
  a. what kind of a bond is formed? b. are ions formed?

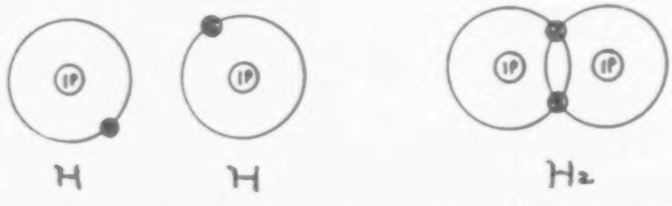
6-19 When a nonmetal bonds to a nonmetal,
  a. what kind of a bond is formed? b. are ions formed?

6-20 A bromine atom has seven outermost electrons. How many electrons of its own must a bromine atom share with another bromine atom to obtain a stable octet of electrons?

6.5 B COVALENT HYDROGEN

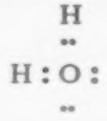
The hydrogen atom is very versatile: it can act as a metal and lose its one electron to form the ion, H^+. It can act as a nonmetal and form one covalent bond with an element like carbon.

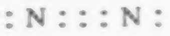
In the elemental state, hydrogen is too reactive to exist by itself. It has its own single electron and can share one from another hydrogen atom to form a stable particle made up of two hydrogen atoms covalently bonded. Hydrogen gas is made up of H_2 particles.

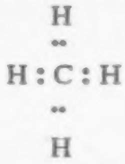


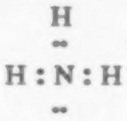
The two electrons around a hydrogen atom are called a ***DUPLET***.

When hydrogen bonds to form a duplet, it has the same electron configuration as helium. The duplet causes both helium and the covalently bonded hydrogen particle to be stable. Hydrogen is the only element which can bond covalently to form a duplet rather than an octet. Following are diagrams of some small covalent particles. In these diagrams, the inner filled electron shells are omitted. The outer electrons are shown in pairs around the atom. Notice that each hydrogen atom has a duplet and each other atom has an electron octet.


water


elemental nitrogen


methane


ammonia

Exercise 6.5 B

6-21 a. How many electrons are needed to form a stable duplet?
b. How many electrons of its own must a hydrogen atom share to become stable?
c. Sugar is made up of carbon, oxygen, and hydrogen. What kind of bonding does it have? Explain.

Section 6.6 MOLECULES

A neutral particle made up of two or more atoms held together by covalent bonding is called a ***MOLECULE.***

The chlorine molecule consists of two chlorine atoms held together by one covalent bond. The chemical formula of the molecule is Cl_2. The subscript, 2, shows that there are two atoms of chlorine in the molecule. *A* ***SUBSCRIPT*** *in a chemical formula tells how many atoms there are of the element that it follows.* The form in which elemental chlorine exists at room temperature is Cl_2. The hydrogen molecule has the formula, H_2.

There are gaseous, liquid, and solid covalent molecules of all kinds. The water molecule, for example, has two atoms of hydrogen each covalently bonded to one atom of oxygen, H_2O. There are molecules that contain hundreds of bonded atoms with many different elements in them. The proteins in your body contain hundreds of atoms including carbon, hydrogen, oxygen, nitrogen, and sulfur.

Some molecules contain atoms which share two pairs or three pairs of electrons between them in one combined bond. In each case, the shared pairs of electrons complete the octet for each of the bonded atoms. The number of covalent compounds that can be formed approaches the infinite; there are many more covalent compounds known than there are ionic.

As with ionic compounds, the chemical and physical properties of a compound are usually quite different from those of its elements. Just about all substances which are liquid or gaseous at room temperature are bonded covalently and exist as molecules. Many solids are also made up of molecules.

Most covalent molecules are poor conductors of electricity. In order to conduct electricity, a substance needs bonding electrons or ions which can easily be pushed from one part of it to another part or to another particle. Molecules do not have ions; electron pairs in purely covalent bonds are held too firmly to allow electrical conductivity.

Exercise 6.6

6-22 Which "2" is a subscript in $C_2O_4^{2-}$? What does the subscript mean?

6-23 Write the formula of a molecule of
a. chlorine; b. hydrogen.

(Exercise 6.6 is continued on the next page)

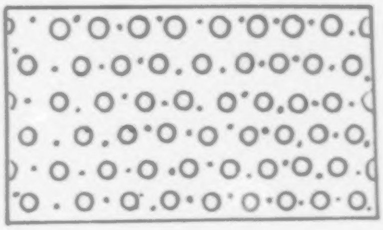
6-24 What type of bond is formed when
- a. calcium (column IIA) bonds to fluorine (column VIIA)?
- b. sulfur (column VIA) bonds to fluorine?

6-25 What kind of bonding does each of the following compounds have?
- a. calcium bromide
- b. phosphorous trichloride
- c. sodium oxide
- d. lithium nitride
- e. carbon tetrachloride
- f. sulfur difluoride
- g. nitric oxide
- h. water
- i. rubbing alcohol

Section 6.7 THE METALLIC BOND

So far, the bonding in compounds and in the elemental gases has been discussed. What kind of bonding does a metal have?

Metals are good conductors of heat and electricity and are mostly hard shiny solids. These properties can be explained by the theory that they have loosely held outer electrons. They have one, two, or three outer electrons which are farther out than any others on the atoms. We know that the outer electrons can be pulled off by certain nonmetal atoms to form ions. Other evidence also suggests that these electrons are not very tightly held.



In the elemental state, metallic atoms are arranged in orderly layers in the solid. The outermost electrons (one, two, or three) of each metallic atom are attracted both to their own nucleus and to the ones adjacent. The electrons dance back and forth between the atoms, and are shared by all the atoms around them, existing of a sort of "sea of electrons." The attractions between the mobile electrons and the positive cores of the atoms bond the atoms together.

Electricity is easily conducted by metals because the outer electrons can be pushed from one atom to another atom on and on through the metal.

Exercise 6.7

6-26 Given a metallic solid, where are the outermost electrons situated in the crystal?

6-27 Why do metals conduct electricity easily?

6-28 Which of the following would you expect to easily conduct electricity?
- a. copper metal
- b. alcohol
- c. mercury
- d. hydrogen
- e. methane, the gas in your laboratory burners

Section 6.8 ORGANIZED CHEMICAL KNOWLEDGE

This chapter has examined some of the ways in which organized information in science can lead to predictions. The periodic table and the modified Bohr theory make it possible to predict for many elements the charges on ions, the types of bonding an element will have, the physical state of an element or compound, and whether the liquid or solid can easily conduct electricity. Facts and theory tie together to explain and to predict chemical behavior.

The organization of chemical knowledge makes use of ordering, classification, and modeling. We have seen that the periodic table shows elements in order of their properties and classifies them vertically according to similarities. The Bohr theory includes models. From these relationships, humans are able to perceive patterns of knowledge and to use them to expand their understanding of nature.

Activity 6 . 1 BONDING

Purpose: to identify the bonding in a substance by its conductivity in pure water
Materials: 9 volt battery (students bring from home, type used in cassettes and calculators), battery snap, masking tape, deionized (or distilled) water, 50 mL beaker or jar, stirrer and the following compounds:

Name	Elements present	Name	Elements present
table salt	Na,Cl	borax	Na,B,O
baking soda	Na,H,C,O	aspirin	C,H,O
epsom salt	Mg,S,O	table sugar	C,H,O
rubbing alcohol	C,H,O	glycerine	C,H,O

Discussion: Electricity can be conducted in matter if charged particles are present which are free to move and carry the charge from one part of the material to another. Solid ionic substances do not conduct electricity because the ions are tightly bound by the attractive forces and cannot move out of place. In water solution, however, the ions separate, move out of place, and can carry charge from one place to another, so water solutions of ions conduct electricity. Covalent substances have no ions to carry charge so they act as nonconductors both in the pure state and in water. This makes conductivity in water a diagnostic test for finding out whether or not bonding is ionic.

Just as medical tests are not perfect, this diagnostic test for bonding is not perfect. Some covalent substances do conduct in water for special reasons, and some ionic substances are too insoluble to conduct. You will use the conductivity test to suggest the type of bonding within each substance being tested.

Procedure:

Step 1: Prepare a chart like the one given below to record your data.
Extend the columns as needed.

CHART OF CONDUCTIVITY

Common Name	Elements present	Conducts? yes/no	Ionic? yes/no	Metal in it? yes/no	Nonmetals in it? yes/no

Step 2 :

1. Wear your goggles.
2. Obtain the snap wire and a battery.
3. Construct an electricity tester as follows. Remove ½ cm from the end of each battery snap wire. DON'T allow the wires to touch each other during this experiment because it will cause the battery to be quickly used up. Connect your battery to the battery snap. You have made an electricity tester.
4. Obtain the beaker and put about 10 mL deionized water in it. In the next steps, you are going to find out whether substances dissolved in the water cause the solution to conduct electricity. You need to check that the water you are using does not already conduct electricity so, with the wires separated, dip the bare ends of the conductivity tester into the liquid and check it.
5. Set your electricity tester aside with the wires carefully kept apart.

Step 3:

1. Obtain the beaker and put about 10 mL deionized water into it.
2. Add a pinch of table salt to the water.
3. Stir until the salt is all dissolved (none of the solid is visible).
4. Keeping the wires separated, place the bare ends of the electricity tester into the beaker of solution. Observe.
5. Remove the electricity tester.
6. Discard the solution into the sink.
7. Rinse the bare wires of the tester, the stirrer, and the beaker with deionized water.

Step 4:

1. Repeat Step 3 with each of the other samples besides salt to determine the conductivity of all the available substances. Begin with a drop of each liquid or a pinch of each solid in a fresh 10 mL water; stir until all of the sample dissolves or until no more seems to dissolve.
2. Also, test 10 mL deionized water by itself.

Questions:

Q. 1 What evidence can you see of any conductivity shown by your testing apparatus?

Q. 2 Do all of the substances that conduct electricity have metallic elements in them? (Note: hydrogen acts as a nonmetal in these compounds.)

Q. 3 Suggest another reason besides conductivity to believe that rubbing alcohol and glycerine are not ionic compounds.

Q. 4 Why was it important to test the deionized water?

Q. 5 Besides composition and taste, how else is table salt different from sugar?

Chapter 6 Review

Vocabulary

Chemical Bond
Metallic Bond
Ionic Bond
Covalent Bond

Match the bonds above with the phrase which best describes them in items 1-7 below. Each type of bond may be used more than once.

1. holds together particles forming metal-nonmetal combinations
2. the sharing of two electrons between two atoms
3. a general name for the ties which hold atoms together in a stable combination
4. holds together the atoms of solid elements found on the left side of the periodic table
5. holds charged particles of different elements together
6. type of bond where four electrons are shared between two atoms
7. bonds ions of opposite charges

Choose the best word from the list below to complete each sentence in items 8-16.

neutral
molecule
outer electrons
superscript
octet
subscript
negative ions
binary compound
duplet

8. A ____________________ after a chemical symbol indicates the number of atoms of an element present in the substance.
9. The stable outer electron configuration of Cl^- is referred to as a(n) ____________________ .
10. When bonded ionically, we would expect nonmetal atoms to be present as ____________________ .
11. The stability of a hydrogen atom which is bonded covalently is due to its electron ____________________ .
12. The ____________________ in a metallic solid can be moved from one atom to the next one.
13. When atoms are bonded covalently to form a neutral particle, the atoms form a ____________________ .
14. The quantity of charge on an ion in its formula is shown by a(n) ____________________ .

*15. A(n) ____________________ contains only two elements.

*16. An ionic solid appears to be ____________________ because the total positive charge is equal to the total negative charge.

Applications

For items 1-5, pick all of the following which apply. Each choice may be used more than once.

a. outermost electrons
b. innermost electrons
c. neutrons
d. forms crystals made of charged particles
e. both metals and nonmetals
f. often conducts electricity in water solution
g. shares nuclear protons
h.. involves only metals
i. neutral atoms held together
j. forms molecules

1. Which are involved with ionic bonding?
2. Which are involved with covalent bonding?
3. Which are found with metallic bonding?
4. Which are not involved in chemical bonding?
5. Which of the choices apply to both ionic and covalent bonding?

Label each of the following statements 6-13 as true or false. If the statement is FALSE, REWRITE the capitalized words to make it a true statement.

6. Atoms of SODIUM, POTASSIUM, CHLORINE, AND SULFUR readily form positive ions.

7. NONMETALS can join together to form covalent molecules.

8. The Bohr model for helium shows two electrons in its single energy level. This is referred to as a DUPLET.

9. When an atom loses electrons, it becomes a NEGATIVE ion.

10. The number of ELECTRONS in a compound is shown by a subscript.

11. Sulfur reacts with oxygen to form a COVALENT compound.

12. Sulfur CAN chemically bond with sodium.

13. Elements in Column VIA can GAIN OR SHARE ELECTRONS.

Items 14-28 are multiple choice. Choose the best answer to complete the statement or answer the question.

14. Which of the following DOES NOT have a duplet electron configuration?
    a. H_2; b. He; c. H^+; d. choices a, b, and c all have a duplet

15. An atom contains 13 protons, 14 neutrons, and 10 electrons. It is
    a. a positive ion.
    b. neutral.
    c. a negative ion.

16. An ion is made of 15 protons, 16 neutrons, and 18 electrons. It has a charge of
    a. +3; b. +1; c. 0; d. −1; e. −3.

17. A certain element has 32 protons and 40 neutrons. To form an ion with a charge of +2, it must
    a. gain two protons.
    b. lose two protons.
    c. gain two electrons.
    d. lose two electrons.

18. Which is the combination that forms an ionic bond?
    a. oxygen and hydrogen
    b. oxygen and sulfur
    c. oxygen and chlorine
    d. oxygen and lithium

19. In chemical bonding, metals which bond to nonmetals
    a. gain electrons.
    b. lose electrons.
    c. share electrons.
    d. both a and c are possible answers.

20. Which of the following conduct electricity?
    a. chlorine gas
    b. ions in solution
    c. solid iron
    d. sugar crystals
    e. both b and c

21. Which of the following combinations bonds covalently?
    a. phosphorus and chlorine
    b. aluminum and chlorine
    c. lithium and chlorine
    d. calcium and chlorine

22. Choose the best words to describe the type of bonding within a bar of gold.
    a. electron sharing
    c. sea of electrons
    b. negative ion formation
    d. crystal formation

23. Calcium is not expected to form bonds with
    a. oxygen; b. sulfur; c. fluorine; d. xenon.

24. Negative ions within an ionic crystal DO NOT repel each other because each negative ion
    a. contains a stable electron configuration.
    b. has been balanced by a proton.
    c. shares electrons with another.
    d. is surrounded by positive ions.

25. The electrons which are most important in bonding are the
    a. innermost.
    b. outermost.
    c. sometimes the innermost and sometimes the outermost.

26. An element located in Column VIIA (seven outer electrons) tends to form an ion with a
    a. +1 charge; b. +2 charge; c. −1 charge; d. −2 charge.

*27. A metallic element with one outermost electron can become stable if it
    a. gains 1 electron.
    c. shares one electron.
    b. loses 1 electron.
    d. gains one proton.

*28. A metal may be defined as an element which gains electrons on bonding.
    a. true; b. false

Items 29-32 require short answers. Use your periodic table when necessary.

*29. Name the binary compounds of
    a. sodium and sulfur; b. oxygen and rubidium.

*30. What is one test to distinguish between ionic and covalently bonded substances in solution in the laboratory?

*31. Complete the following table.

Element	Number of e− in atom	Number of e− in ion	Number of e− lost	Number of e− gained	ion formed
Br	35	36	--	1	Br^{-1}
N	7				N^{-3}
	20	18		--	
Li	3				

*32. State whether oxidation or reduction takes place for each of the following.
    a. Na forms Na^+
    c. sulfur forms the sulfur ion
    b. Cl forms Cl^-
    d. aluminum forms the aluminum ion

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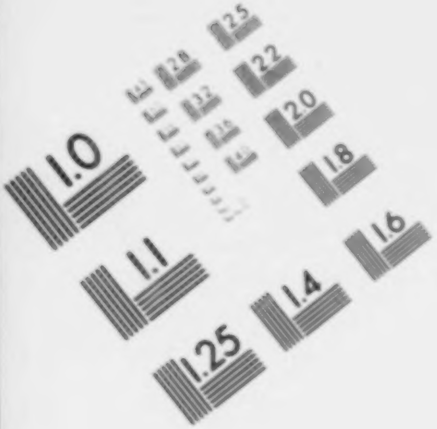
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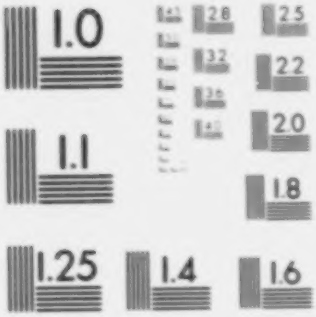
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3.6
4.0

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    c. sea of electrons
    b. negative ion formation
    d. crystal formation

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    b. has been balanced by a proton.
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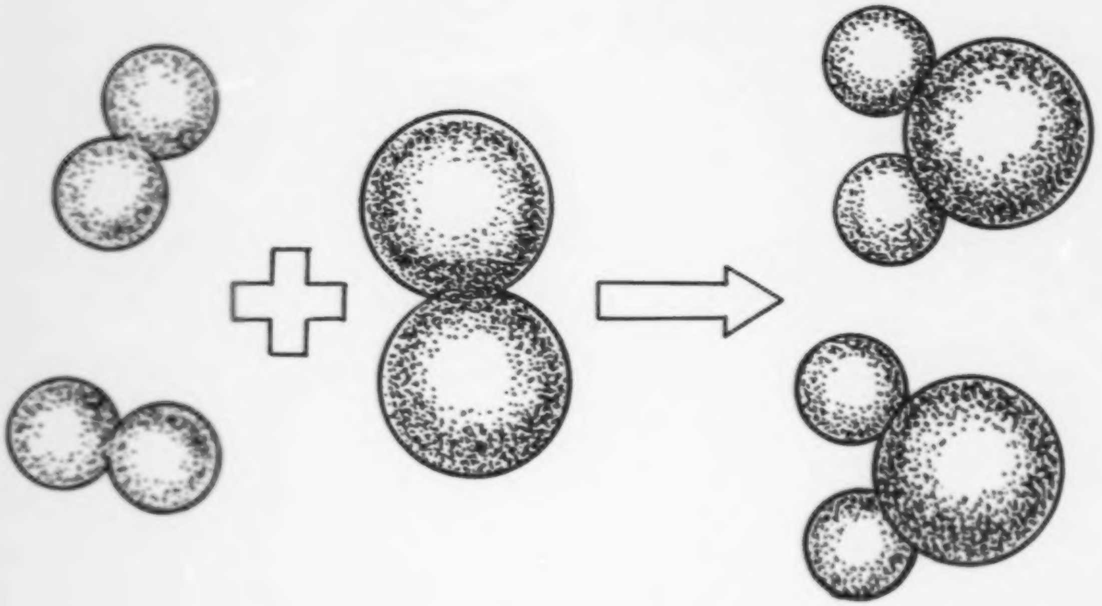
7



FORMULAS AND EQUATIONS

Section 7.1 FORMULAS

Below are two simple formulas and their meanings in words.

Formula	Meaning
NaCl	sodium chloride, a compound made up of one atom of sodium for each atom of chlorine
Cl_2	elemental chlorine, two atoms of chlorine per molecule

As you can see, a formula is chemical shorthand for the words needed to describe the elements in a substance and to show the number of atoms of each element in the formula.

Formulas can be used to show the identity of a material. For example, you can say H_2O instead of saying *water*. Instead of writing *table salt*, you can write *NaCl*. It doesn't matter how much water you are talking about, whether a single molecule or a ton of water, the formula stands for the water. Likewise, it doesn't matter how much salt you are writing about; any quantity of it is called NaCl.

water mizu woeter áqua
mayim su
vann víz veso wasser
wai
akvo unda H_2O shuí

In the next sections, you will see how the formulas for elements and compounds are written, and how these formulas are used in the shorthand which describes chemical reactions.

Exercise 7.1

7-1 What is the difference between a chemical symbol and a chemical formula?

7-2 Given that the formula of a shipment of copper sulfate is $CuSO_4$, can you tell the quantity of the $CuSO_4$ from this?

7-3 Can a chemist write the formula for a mixture of salt and sugar? Explain.

Section 7.2 FORMULAS OF THE ELEMENTS

The formulas for elements in their natural state identify them as they exist at room temperature.

7.2 A FORMULAS FOR ELEMENTS WHICH EXIST AS DIATOMIC MOLECULES IN THE NATURAL STATE

Molecules that are made up of two atoms each are called ***diatomic molecules.***

Certain elements exist naturally as diatomic molecules; they are all nonmetals. Five are gases, one is a liquid, and one is a solid.

1. The Diatomic Elemental Gases

   All of the elemental gases exist as diatomic molecules except for the noble gases. The following are the diatomic elemental gases.

   $$H_2, N_2, O_2, F_2, \text{ and } Cl_2.$$

   The subscript in a chemical formula tells how many atoms there are of the element that it follows. Put each of the above formulas into your periodic table to help you learn them.

2. Liquid bromine and solid iodine

   Liquid bromine and solid iodine, both of which are halogens (Column VIIA), exist as diatomic molecules at room temperature. The formulas are:

   $$Br_2 \text{ and } I_2.$$

7.2 B ALL OTHER ELEMENTAL FORMULAS ARE SHOWN BY THE ATOMIC SYMBOL

Except for the diatomic molecules, the formula for each of the other elements is given simply by its symbol. These elemental formulas include the

1. noble gases: **He, Ne, Ar, Kr, Xe,** and **Rn**
2. solid nonmetals: *e.g.,* **C** for carbon, **S** for sulfur, and **P** for phosphorous.
3. metals (and metalloids): *e.g.,* **Li** for lithium, **Hg** for mercury, **Au** for gold

Exercise 7.2

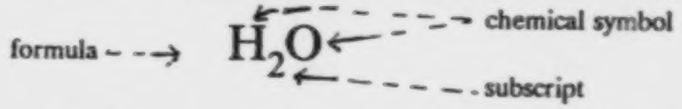
7-4 Write the formulas for the elemental state of the following elements.

a. oxygen
b. magnesium
c. fluorine
d. nitrogen
e. tin (atomic number 50)
f. neon
g. potassium
h. hydrogen
i. carbon

Section 7.3 FORMULAS OF COMPOUNDS

7.3 A RULES FOR FORMULAS OF COMPOUNDS

The formulas of compounds use the symbols of the elements to show which are in the compound and use a subscript to indicate how many atoms of each are in the formula. For example, the formula of water has 2 atoms of hydrogen for each atom of water.



When there is only one atom of an element present in the formula, the subscript, 1, is omitted; you know it is there but it is invisible.

Thus, the symbol for oxygen in the above formula has an invisible "1" after it. Similarly, the compound sulfur dioxide, SO_2 has one atom of sulfur per two atoms of oxygen. Sodium chloride, NaCl, has the invisible subscript, 1, after each symbol.

Exercise 7.3 A

7-5 How many atoms of each element are present in the formula for sodium carbonate, Na_2CO_3?

7-6 How many atoms of each element are present in the formula of table sugar, $C_{12}H_{22}O_{11}$?

7.3 B COMPOUNDS HAVE CONSTANT COMPOSITION

Water, H_2O, always has the same composition. It has two atoms of hydrogen per one atom of oxygen no matter how many molecules are present.

PER means *for each or for every.*

The **per relationship** of

2 atoms of hydrogen for each 1 atom of oxygen,
2 atoms of hydrogen per molecule of water, and
1 atom of oxygen per molecule of water

always holds no matter how much water there is.

Likewise, table salt has one atom of sodium per one atom of chlorine no matter how big the crystal is.

All compounds have constant composition. That is, the per relationships in a compound are always the same for that compound.

Covalent compounds such as sugar exist as molecules. Ionic compounds do not exist as molecules but rather as huge networks of ions. Even so, the numbers of each ion always have the same per relationship to each other. No matter how big a crystal of table salt is selected, there is always one sodium ion per one chloride ion.

Rubbing alcohol, C_3H_8O, always has 3 atoms of carbon
per 8 atoms of hydrogen
per 1 atom of oxygen
per one molecule of rubbing alcohol

no matter how much rubbing alcohol is present.

Formulas do not tell you whether a molecule or a network is present. Chemists know by looking at the elements in the formula whether the bonding is most likely to be covalent or ionic.

Exercise 7.3 B

7-7 In the following compounds, state how many atoms of each element are present in the formula for that compound.

a. $K_2Cr_2O_7$; b. H_2O_2; c. KBr

7-8 Which of the compounds in 7-7 are made up of ions and which are made up of molecules? (Hint: hydrogen acts as a nonmetal in b.)

7.3 C DIFFERENT COMPOUNDS MAY BE MADE OF THE SAME ELEMENTS

Different compounds may have the same elements in them but still differ because the per relationships differ. For example, the following compounds of nitrogen and oxygen are all different.

laughing gas,	N_2O	2 atoms of nitrogen per 1 of oxygen
nitric oxide,	NO	1 atom of nitrogen for 1 of oxygen
nitrogen dioxide,	NO_2	1 atom of nitrogen for every 2 of oxygen

Exercise 7.3 C

7-9 Are H_2O and H_2O_2 the same compound? Explain.

7.3 D THE COEFFICIENT OF A FORMULA

Up until now, the formula has always referred to any quantity of the substance. However, a formula can be written so that it refers to only one of whatever it is describing. This happens whenever a number is placed in front of it. Thus,

1 NaCl means a total of one sodium atom and one chlorine atom present.

2 NaCl means 2 x 1 NaCl, or 1 NaCl + 1 NaCl with a total of two sodium atoms and two chlorine atoms.

The ***COEFFICIENT*** *of a formula is a number which multiplies the formula that directly follows it.*

It is often convenient to use the term, **FORMULA UNIT** to describe *"1 formula"* of a substance; for example, one formula unit of sodium chloride is 1 NaCl; 2 NaCl means two formula units of NaCl. Likewise,

3 $CaCl_2$ means three formula units of calcium chloride totalling three calcium atoms and six chlorine atoms.

2 $Na_2Cr_2O_7$ means two formulas units each made up of 2 Na atoms, 2 Cr atoms, and 7 O atoms, totalling 4 Na atoms, 4 Cr atoms, and 14 O atoms.

Exercise 7.3 D

7-10 a. How many atoms of each element are present in 2 Na_2CrO_4?

b. How many atoms of sodium are present per atom of chromium (Cr)?

7-11 State the total number of atoms for each of the following.

a. 4 NaCl; b. 3 H_2O; c. 2 H_2SO_3

Optional: Section 7.4 FORMULAS OF IONIC COMPOUNDS

Recall that a **BINARY COMPOUND** is made up of only *two elements*. Some logical rules can be used to write the formulas of ionic binary compounds.

When ions combine to form a neutral compound, the following must be true; total positive charge is balanced by total negative charge. Therefore,

total positive charge = total negative charge

For example, if Na^+ reacts with Cl^-, the positive charge on one ion of sodium can be balanced by the negative charge on one ion of Cl^-. The total charge on one NaCl formula unit can be calculated as

$$(1+) + (1-) = 0.$$ The unit is neutral.

If magnesium ion, Mg^{2+}, reacts with Cl^-, the charge of 2+ on the Mg^{2+} cannot be balanced by one Cl^-. The Mg^{2+} needs two Cl^- per Mg^{2+} so that $(2+) + (2 \times 1-) = 0$. Thus, the formula for magnesium chloride must be $MgCl_2$

By balancing the charges, the formulas for compounds (which are all neutral) can be worked out. However, there is an easy shortcut to calculate formulas of binary ionic compounds. The rules are given below followed by an example.

Rules for Formulas of Binary Compounds

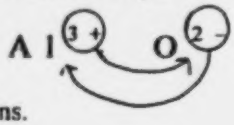
1. Write the formulas of the two ions next to each other with their correct charges; the metallic ion is always written first.
2. Cross over the numbers to become subscripts.
3. Delete the plus and minus signs.

This is illustrated next for the compound of aluminum (Al) and oxygen (O) called aluminum oxide. Aluminum oxide forms the dull coating on aluminum pans. Aluminum itself is a shiny metal. The ions present in aluminum oxide are Al^{3+} and O^{2-}.

1. Write the formulas of the two ions, with the metallic ion first.

$$Al^{3+} \quad O^{2-}$$

2. Cross over the 2 and 3 to become subscripts



3. Delete the plus and minus signs.

$$Al_2O_3$$

Let us check that Al_2O_3 has a total charge of zero (that it is neutral).

The total positive charge is $2(3+) = 6+$.
The total negative charge is $3(2-) = 6-$.

$$(6+) + (6-) = 0$$

The compound formed is neutral.

If the subscript in the formula is 1, just leave it out after crossing over since the 1 should be invisible. Keep in mind that the subscript always applies to the element it follows.

In the special case where both elements in the formula each have a subscript of 2 or each have 3, reduce each subscript to 1. For example, magnesium sulfide turns out to have the formula, Mg_2S_2 by this method. Divide both subscripts by 2 to arrive at the formula MgS showing that there is one atom of magnesium per one atom of sulfur.

Exercise 7.4

7-12 In formulas containing a metallic and a nonmetallic element, which is written first?

7-13 a. Write the formulas of the compounds of each of the following:

(1) K^+ and Br^-
(2) Cl^- and Mg^{2+}
(3) I^- and Al^{3+}
(4) Ba^{2+} and O^{2-}
(5) Ca^{2+} and S^{2-}
(6) Al^{3+} and O^{2-}
(7) Na^+ and P^{3-}
(8) Mg^{2+} and N^{3-}

b. Check your answers to a. (1) to (4) by showing that the sum of the positive charges equals the sum of the negative charges in the formulas.

7-14 Use a periodic table as needed to find the charges on the ions of the elements and then write the formulas of the compounds formed by

a. lithium and fluorine .
b. rubidium (atomic number 37) and oxygen .
c. strontium (atomic number 38) and chlorine.
d. aluminum and sulfur (atomic number 16).
e. lithium and nitrogen .

Section 7.5 SHORTHAND FOR CHEMICAL REACTIONS

7.5 A THE WORD EXPRESSION AND THE SHORTHAND EXPRESSION

The substances which react with each other in a chemical reaction are called the ***REACTANTS***.

The substances which are produced are called the ***PRODUCTS***.

The reactants are always shown at the left in the word expression for a chemical reaction. The products are always listed at the right.

Reactants yield products.

For example, when elemental sodium and chlorine react to form sodium chloride, sodium and chlorine are the reactants and sodium chloride is the product. The word expression for this reaction is,

sodium plus chlorine yield sodium chloride.

Similarly, the word expression for the reaction of elemental hydrogen and oxygen to form water is

hydrogen plus oxygen yield water.

Shorthand expressions may be written for chemical reactions using the formulas for the substances and an arrow for the word *yield.*

The reaction to form water from its elements can be written in chemical shorthand as (note that hydrogen and oxygen exist as diatomic molecules in the natural elemental state)

$$H_2 + O_2 \longrightarrow H_2O$$

Exercise 7.5 A

7-15 For a chemical reaction, what is meant by

a. a word equation?
b. reactants?
c. products?
d. yield?

(Exercise 7.5A is continued on the next page)

For 7-16 and 7-17 below, use the knowledge that one atom of carbon combines with one atom of oxygen to form a molecule of carbon monoxide.

7-16 a. Write the word statement for this reaction.

b. Make a drawing to show that one atom of carbon plus one atom of oxygen form carbon monoxide. Use round circles for each atom with its symbol inside. Use the plus sign where needed. Instead of the word *form*, use the yield sign, $\longrightarrow$

7-17 If two zillion atoms of carbon are reacted with oxygen, how many atoms of oxygen combine with the carbon?

7.5 B. EQUATIONS FOR CHEMICAL REACTIONS

The expression at the end of Section 7.5 A,

$$H_2 + O_2 \longrightarrow H_2O\ ,$$

is not a chemical equation. An equation means that the left side of the expression equals the right side. The left side of this expression shows two atoms of hydrogen and two atoms of oxygen. The right side shows two atoms of hydrogen but only one atom of oxygen.

**Q. 1 How many atoms of oxygen need to be shown in the right side of the above expression to make it an equation?

Whenever a chemical reaction takes place, all the substances are mixed together. All of the atoms that are present at the beginning must be present when the reaction is over. The atoms have only changed partners or acquired partners or separated from partners. The number of atoms of each element does not change during a chemical reaction.

THE TOTAL NUMBER OF ATOMS OF EACH ELEMENT MUST BE THE SAME ON BOTH SIDES OF A CHEMICAL EQUATION.

When the total number of atoms of each element shown in a reaction expression is equal on both sides, the expression is said to be ***BALANCED***. It is a chemical equation.

The expression for the water reaction, $H_2 + O_2 \longrightarrow H_2O$, is UNBALANCED.

A COEFFICIENT MAY BE PLACED IN FRONT OF A FORMULA IN AN UNBALANCED REACTION EXPRESSION TO HELP MAKE IT INTO AN EQUATION. When the coefficient is the number "one", it is omitted. The reader is expected to know that there is an invisible one wherever there is no coefficient.

The chemical equation, or balanced expression, for the formation of water from its elements is

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Notice that there is an invisible "1" in front of the oxygen. To check that this is an equation, let's count the atoms on each side of the yield sign. There are

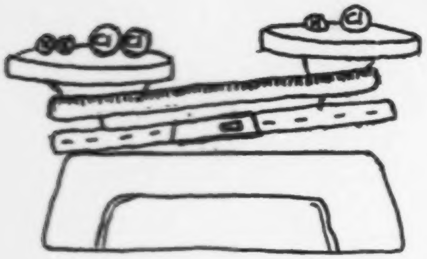
4 hydrogen atoms and 2 oxygen atoms to the left of the arrow, and
4 hydrogen atoms and 2 oxygen atoms to the right of the arrow.

The number of atoms of each element is the same on both sides.

The formula itself may **NOT** be changed to help balance a reaction expression.

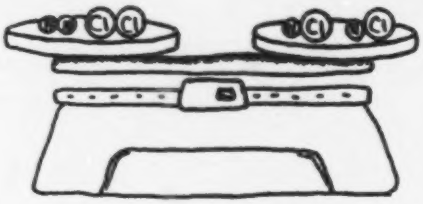
Any change in the formula changes the identity of the compound. Coefficients are used to balance equations.

Reaction: Hydrogen plus chlorine yield hydrogen chloride



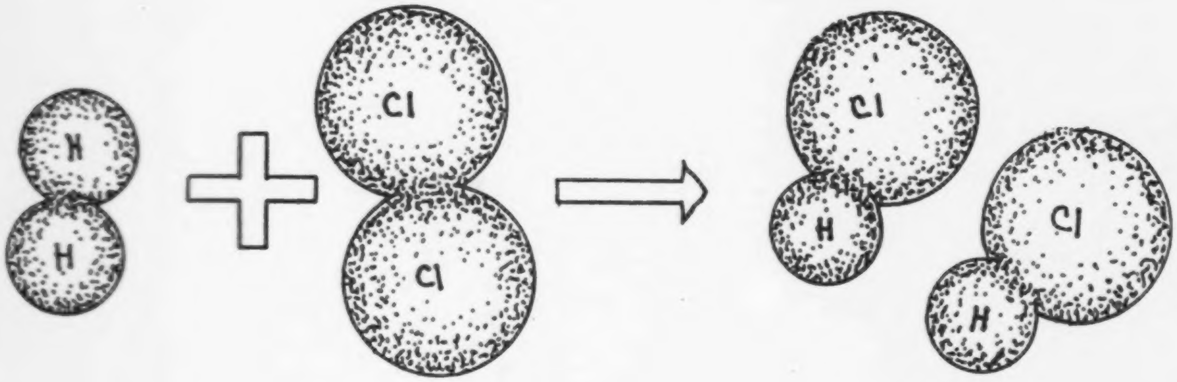
Unbalanced expression

$H_2 + Cl_2 \longrightarrow HCl$



Balanced expression

$H_2 + Cl_2 \longrightarrow 2\ HCl$



The following examples show how to recognize when a reaction expression is balanced, that is, when it is an equation.

Example 7.1

Problem: Is the following expression an equation?

$$2\ Na + O_2 \longrightarrow 2\ Na_2O$$

Solution: To answer this question, count the numbers of atoms of each element on the left hand side of the equation. Repeat for the right side. If it is an equation, they should be the same.

Reactants	Products
2 Na	$2\ Na_2 = 4\ Na$
O_2	2 O

The sodium atoms are not equal on both sides. The expression is not balanced.

Example 7.2

Problem: Is the following expression an equation?

$$4\ FeS_2 + 11\ O_2 \longrightarrow 2\ Fe_2O_3 + 8\ SO_2$$

Solution: To answer this question, count the numbers of atoms of each element on the left hand side of the equation. Repeat for the right side. If it is an equation, they should be the same.

Reactants	Products	
4 Fe	$2\ Fe_2 = 4\ Fe$	checks
$4\ S_2 = 8\ S$	8 S	checks
$11\ O_2 = 22\ O$	(Oxygen appears in two formulas. The sum is needed.) For the products, $2\ O_3 + 8\ O_2 = 6\ O + 16\ O = 22\ O$	checks

The expression is an equation.

Exercise 7.5 B

Are the following expressions equations? Show your work as in the sample problem above.

7-18 $C + O_2 \longrightarrow CO_2$

7-19 $C + O_2 \longrightarrow CO$

7-20 $2\ Na + Cl_2 \longrightarrow NaCl$

7-21 $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$

7-22 $4\ Fe + 3\ O_2 \longrightarrow 2\ Fe_2O_3$

7-23 $HCl + NaOH \longrightarrow NaCl + H_2O$

7-24 $H_2SO_4 + 2\ NaCN \longrightarrow 2\ HCN + Na_2SO_4$

7-25 $2\ Al + 3\ CuCl_2 \longrightarrow 2\ AlCl_3 + Cu$

7-26 $Mg + HCl \longrightarrow H_2 + MgCl_2$

Answer to Q
Q.1 two atoms of oxygen

*Activity 7.1 MODELS OF COVALENT REACTION EQUATIONS

Purpose: to construct models of equations for reactions
Materials: polystyrene, or half-polystyrene spheres with a cardboard and glue, or gum drops with pipe cleaners or toothpicks as connectors
Discussion: You will use your materials to construct models for the assigned reactions. In each, a sphere or gum drop stands for an atom; a connector stands for the covalent bond. The assigned reaction expressions are not balanced. To balance a reaction expression, keep adding

more of any of the reactants as needed and/or add more of the product produced. However, you can only add whole molecules; you cannot break up a molecule to add it. For example, if H_2 is a reactant or product, you cannot add H, only H_2; if H_2O is a reactant or product, you cannot add H, H_2, or O, only H_2O.

Procedure:

Make models for the following reactions. Be sure that the models show a balanced reaction expression.

(1) $C + H_2 \longrightarrow CH_4$

(2) $N_2 + H_2 \longrightarrow NH_3$

Your teacher will tell you how to get your models approved.

Question:

In reaction (1), if one atom of carbon reacts, what is the total number of atoms involved in the reaction?

Optional: Section 7.6 HOW TO BALANCE A CHEMICAL EXPRESSION

In order to write a chemical equation, the chemist must first know the reactants and products. Although a chemist can often make a very good guess as to the products, the only sure way to know is when the chemicals have actually been reacted and the products identified. Also, to write the equation, the formulas of the reactants and products must be known.

Given the identities and formulas of the reactants and products, the expression for the reaction can be written and balanced. Many reaction expressions can be balanced simply by trying out one or two coefficients on them. For this method, there are two essential steps which may need to be repeated several times.

1. **Count the atoms of each element on each side of the equation to see if the expression is balanced.**
2. **Add one or more coefficients where it helps.**

Example 7.3

Problem: What is the equation for the reaction of nitrogen with oxygen to produce nitrogen monoxide? The expression for this is

$$N_2 + O_2 \longrightarrow NO$$

Solution:

Count the atoms of each element on each side of the equation to see if the expression is balanced. There are 2 N and 2 O on the left but only 1 N and 1 O on the right. The expression is not balanced.

Add a coefficient where it looks as if it might help. Since, the right side of the equation has only one nitrogen atom, place the coefficient, 2, in front of the NO. This doesn't change the formula of NO but changes the number of molecules produced. The expression now shows that two molecules of NO are produced per one molecule of N_2 and one molecule of O_2.

$$N_2 + O_2 \longrightarrow 2\,NO$$

Recount the atoms. Now, there are 2 N and 2 O at the left and 2 N and 2 O at the right. The expression is balanced.

Sometimes, all the coefficients have to be changed one by one from the invisible 1 to another number. To balance them, keep comparing numbers of atoms of each element on left and right and try some coefficients. Here's another example.

Example 7.4

The unbalanced expression for the reaction of black iron oxide and hydrogen to give iron and water is

$Fe_3O_4 + H_2 \longrightarrow Fe + H_2O$. Write the equation.

Solution:

First, count the atoms on each side of the equation. There are three Fe at the left but only one Fe at the right. Place a coefficient of 3 in front of the lone Fe on the right. Now, Fe is balanced.

$$Fe_3O_4 + H_2 \longrightarrow 3\,Fe + H_2O$$

Continue counting the atoms. There are four O at the left and one O at the right. Place a coefficient of 4 in front of the H_2O. (Notice that you can't just place the 4 as a subscript for the O itself. That would change the formula of the water and change its identity.) Now, O is balanced.

$$Fe_3O_4 + H_2 \longrightarrow 3\,Fe + 4\,H_2O$$

The Fe and O are balanced. The H has to be checked. There are 2 H at the left and 8 H at the right. Place a coefficient of 4 in front of the H_2 at the left; this gives 8 H and balances the H atoms.

$$Fe_3O_4 + 4\,H_2 \longrightarrow 3\,Fe + 4\,H_2O$$

Make a final check. There are 3 Fe, 4 O, and 8 H on the left. There are 3 Fe, 4 O, and 8 H on the right. The expression is now an equation.

Exercise 7.6

Balance the following expressions.

7-27 $C + O_2 \longrightarrow CO$

7-28 $N_2 + O_2 \longrightarrow NO_2$

7-29 $H_2O \longrightarrow H_2 + O_2$

7-30 $H_2O_2 \longrightarrow H_2O + O_2$

7-31 $SO_2 + O_2 \longrightarrow SO_3$

Section 7.7 POLYATOMIC IONS

POLYATOMIC IONS are charged groups of covalently bonded atoms which stay together as a group in their reactions.

For example, the sulfate ion, SO_4^{2-}, is a polyatomic ion made up of one sulfur and four oxygen atoms covalently bonded and with two additional electrons added to the group. The polyatomic sulfate ion is stable and reacts as a group. Many ions form compounds with the sulfate ion such as

$CaSO_4$ Na_2SO_4 $Al_2(SO_4)_3$

Notice that the sulfate group is kept together in the formula. This helps the chemist to recognize the presence of the sulfate ion.

When more than one polyatomic ion is present as in aluminum sulfate, $Al_2(SO_4)_3$, a pair of parentheses is placed around the polyatomic ion. The subscript shows how many particles of the polyatomic ion are in the formula. Hence, in aluminum sulfate, $Al_2(SO_4)_3$, there are three sulfate ions per formula unit and there are 2 Al, 3 S and 12 O atoms present in all.

The following are other polyatomic ions which appear in this book:

ammonium ion NH_4^+ ; nitrate ion NO_3^- ; hydroxide ion OH^- ;
carbonate ion CO_3^{2-}

In compounds, their names appear as in the above. For example, a compound of the ammonium and nitrate ions is called ammonium nitrate.

Exercise 7.7

7-32 How many atoms of each element are present in each of the following?
a. $Ca(OH)_2$; b. NH_4Cl; c. $Al(NO_3)_3$; d. NH_4OH

7-33 Name the compounds in 7-32 a, c, and d.

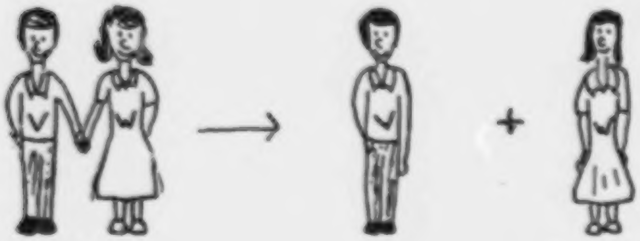
7-34 Name and write the formulas of five polyatomic ions.

Optional: Section 7.8 TYPES OF CHEMICAL REACTIONS

There are several ways to classify chemical reactions. Each way has its advantages in helping chemists to deal with the huge number of known reactions. Many reactions can be classified according to the following scheme.

(1) ***DECOMPOSITION:*** *A single compound is broken down into two or more different substances.* The compound may break down when it is heated, when electrified, in the presence of light or for other reasons. An example of a decomposition reaction is:

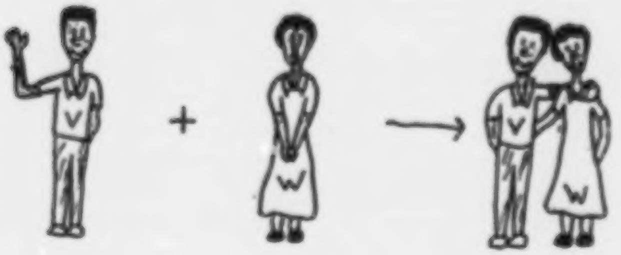
$$2\,H_2O \longrightarrow 2\,H_2 + O_2.$$



Decomposition

(2) ***SYNTHESIS:*** *Two or more elements combine to form a single compound, e.g.,*

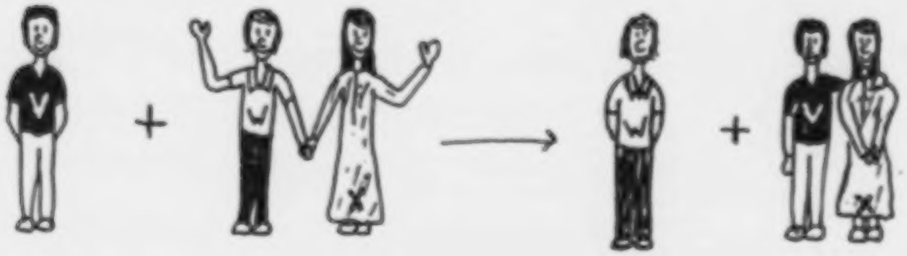
$N_3 + 3\ H_2 \longrightarrow 2\ NH_3$.



Synthesis

(3) ***SINGLE DISPLACEMENT (OR SINGLE REPLACEMENT):*** *An element replaces an element in another compound, e.g.,*

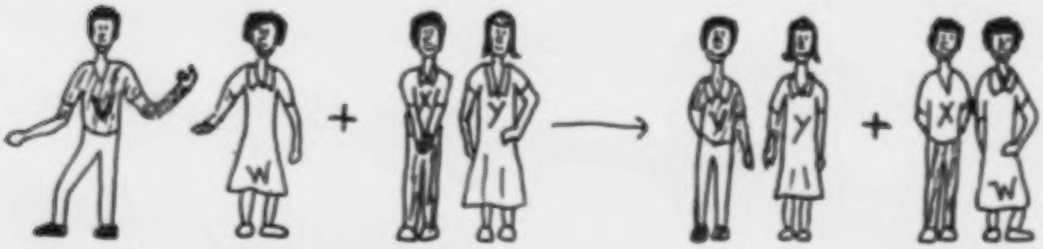
$Mg + 2\ HCl \longrightarrow H_2 + MgCl_2$



Single Displacement

(4) ***DOUBLE DISPLACEMENT (OR DOUBLE REPLACEMENT):*** *Two compounds react and exchange elements, e.g.,*

$HCl + NaOH \longrightarrow NaCl + H_2O$.



Double Displacement

Not all reactions fit into these four classifications nor is this the only way to classify reactions but, like all classification systems, it can come in handy to organize a collection of information.

Exercise 7.8

7-35 Identify each of the reaction expressions in problems 7-18 to 7-31 as a member of one of the above four classifications of reactions.

Activity 7.2 CLASSES OF CHEMICAL REACTIONS

Purpose: to carry out a reaction and to identify its type
Materials: calcium chloride ($CaCl_2$), sodium carbonate (Na_2CO_3), calcium carbonate ($CaCO_3$), dropping bottle of dilute hydrochloric acid (HCl), steel wool, mossy zinc, 3 test tubes, spatula (or scoopula), beaker or test tube rack, matches and candle
Precaution: Acids such as hydrochloric acid can harm skin. Flush off any acid that gets on your skin with sink water. Mop up spills with paper towel. Vinegar is also an acid but is too weak to be harmful to the skin, except to the eyes.
Procedure: Put on a pair of goggles.

Step 1: CALCIUM CHLORIDE AND SODIUM CARBONATE

1. Obtain 3 test tubes, a spatula, and a small beaker or test tube rack.
2. With the spatula, scoop up a bit (size of rice grain) of calcium chloride, and drop it into a test tube. Fill the test tube about one-quarter full of sink water and shake to help the solid dissolve. Place in beaker or test tube rack to support it.
3. Wipe the spatula well with a piece of paper towel and discard the towel into the trash can. Obtain a bit of sodium carbonate as before and likewise dissolve in water in a second test tube. Wipe the spatula clean as before.
4. When the solids have been completely dissolved in each test tube (no solid can be seen), pour the contents of one test tube into the other and shake the mixture gently.
5. After completing your observations, discard any solids remaining in the test tubes into the trash can and flush the test tubes with cold water.

Discussion: The insoluble cloudy material that forms in the water is a solid produced during the reaction called calcium carbonate. The remainder of the reactants have formed a compound with each other which remains dissolved in the water.

Step 2: REACTION TO FORM CARBON DIOXIDE AND WATER

1. Scoop up a bit of calcium carbonate from the desk jar and drop it into a test tube.
2. Add dilute hydrochloric acid to the test tube to cover the calcium carbonate.
3. Let the test tube stand in the beaker or test tube rack. The bubbles that you see are carbon dioxide.
4. Discard any solids remaining in the test tubes into the trash can and rinse the test tubes with sink water.

Discussion:
The expression for the reaction which takes place in Step 2 above may be written in two steps as follows:

$$(1)\quad CaCO_3 + HCl \longrightarrow CaCl_2 + H_2CO_3$$
$$(2)\quad H_2CO_3 \longrightarrow CO_2 + H_2O$$

The common name for H_2CO_3 is carbonic acid.

Step 3: BURNING STEEL WOOL

1. Obtain several strands tangled together of fine steel wool at least 6 cm long, a pair of tongs, and some matches.
2. Hold the end of the steel wool with the tongs. Hold the wool over the sink.
3. Only your partner may be near the sink while you do this. Have your partner light the candle with the match and apply the flame to the steel wool. Blow out the candel when you are done.
4. After you have recorded your observations, clean out the sink and discard trash in the trash can. Return the tongs and extra matches.

Discussion:

When the steel wool burns, it combines with oxygen from the air.

Step 4: ZINC AND DILUTE HYDROCHLORIC ACID

1. Fill a test tube about one-quarter full with dilute hydrochloric acid.
2. Obtain a small piece of zinc and slide it into the test tube.
3. After completing your observations, wash the test tube with the zinc in it well with water. Discard any leftover zinc into the trash can.
3. Return all equipment.

Discussion:

The gas, hydrogen, is formed during this reaction. It comes from the hydrochloric acid, HCl. The Cl part remains in solution. The zinc, of course, does not just disappear. It has reacted with the hydrochloric acid and is now part of a compound with chlorine in solution.

Questions:

Step 1:

1. Write a word equation for the reaction in Step 1.
2. What type of reaction took place in Step 1?

Step 2:

3. What are the two word equations for the reactions in Step 2.?
4. What type of reaction is the first one, (1), in Step 2?
5. What type of reaction is the second one, (2), in Step 2
6. Is expression (1) balanced?
7. Is expression (2) balanced?

Step 3:

8. Write a word equation for the reaction in Step 3.
9. What type of reaction takes place in Step 3?

Step 4:

10. Write a word equation for the reaction in Step 4.
11. What type of reaction takes place in Step 4?

Chapter Seven Review

Vocabulary

Reactant
Yield
Formula
Word Expression
Chemical Equation
Product
Coefficient
Polyatomic

Use the vocabulary words above to fill in the blanks in sentences 1-8 below. Use each word only once.

1. The arrow in a chemical equation means ________________________ .
2. The number of molecules required of each substance in an equation is shown by the ________________________ .
3. An expression is considered a ________________________ when balanced.
4. Any substance on the left side of the ⟶ in a chemical equation is a ________________________ .
5. Subscripts are used to tell the number of atoms of each element in a ________________________ .
6. Water and carbon dioxide are formed during the burning of sugar. Hence, each is a ________________________ of the burning of sugar.
7. A ________________________ is a way to describe a chemical reaction without using formulas.
8. A ________________________ ion has covalently bonded atoms in it.

……

Fill the blanks in sentences 9-12 to complete them. The sentences all refer to the compound, Na_2SO_4.

9. This compound is made up of two atoms of __________ per one atom of __________ per __________ atoms of __________ .
10. A subscript in this formula has been omitted. It is the subscript, __________, which indicates the number of __________ atoms.
11. Na_2SO_4 is the chemical ________________________ for the compound.
12. The number, 4, is a ________________________ which tells the number of oxygen ________________________ in the formula for the compound.

Identify each type of chemical reaction by matching the class of reaction a-d to the chemical equations in items 13-16.

•13. $2\ AgNO_3 + K_2S \longrightarrow Ag_2S + 2\ KNO_3$

•14. $3\ Fe + 2\ O_2 \longrightarrow Fe_3O_4$

•15. $2\ H_2O_2 \longrightarrow 2\ H_2O + O_2$

•16. $2\ Al + 3\ H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3H_2$

a. synthesis
b. decomposition
c. single displacement
d. double displacement

Applications

1. In the following chemical equation:

$$4\ FeS_2 + 11\ O_2 \longrightarrow 2\ Fe_2O_3 + 8\ SO_2$$

   a. underline the subscripts.
   b. put a box around the chemical formulas.
   c. circle the coefficients.
   d. list the chemical symbols for each different element.

2. How many atoms of oxygen are present in
   a. Na_2SO_4; b. $2\ CO_2$; c. $H_2SO_4 + 2\ NaOH$.

3. State the symbol and number of atoms for each element represented in $3\ Ba_3(PO_4)_2$.

4. Write word equations for the following.

   a. $Mg + F_2 \longrightarrow MgF_2$
   c. $2\ Al + 3\ Br_2 \longrightarrow 2\ AlBr_3$
   b. $2\ Sr + O_2 \longrightarrow 2\ SrO$
   d. $2\ Na + Cl_2 \longrightarrow 2\ NaCl$

5. Does a reaction word expression show that atoms are balanced? Explain.

6. Why are subscripts not changed to balance a chemical reaction expression?

Questions 7 - 25 are multiple choice. Choose the best answer for each.

7. A chemical equation must always have the same total on each side of the equation of
   a. atoms.
   b. subscripts.
   c. coefficients.
   d. All of choices a to c are correct.
   e. Only a and c are correct.

8. Which is the correct chemical equation for the word equation:
   liquid bromine plus potassium yield potassium bromide?
   a. $Br + K \longrightarrow KBr$
   c. $K + Br \longrightarrow KBr$
   b. $Br_2 + K \longrightarrow KBr + Br$
   d. $Br_2 + 2\ K \longrightarrow 2\ KBr$

9. Barium nitrate, $Ba(NO_3)_2$ is ionic so it would NOT be expected to
   a. be a molecule.
   b. be electrically neutral.
   c. exist as crystals.
   d. conduct electricity in water solution.

10. The chemical equation for the reaction when iron rusts is:

$$3\,Fe + 2\,O_2 \longrightarrow Fe_3O_4$$

The number of atoms of oxygen per 3 atoms of iron in the reactants is
a. 2; b. 4; c. 3; d. 3/4.

11. The formula which contains a polyatomic ion is
a. Al_2S_3; b. Na_2O; c. $CaCl_2$; d. NaOH.

12. The compound ammonium carbonate, $(NH_4)_2CO_3$, contains all of the following EXCEPT
   a. 14 atoms.
   b. two nitrogen atoms per one carbon atom.
   c. four hydrogen atoms per one carbon atom.
   d. three oxygen atoms per one carbon atom.

13. Potassium and chlorine react together to form a table salt substitute, KCl, according to the reaction: $2K + Cl_2 \longrightarrow 2KCl$. Which of the following is NOT TRUE about this reaction?
   a. Chlorine is shown as a diatomic substance.
   b. The product has two elements in it.
   c. There is one atom of potassium to one atom of chlorine in the product.
   d. The product formed has physical properties which resemble a blend of the properties of the two elements.

14. A chemical formula DOES NOT tell us
   a. the number of atoms in a molecule.
   b. the kinds of atoms in a molecule.
   c. the type of bonding in a molecule.
   d. the per one relationships of atoms in a molecule.

15. Which set of coefficients will make $O_2 + Cu \longrightarrow Cu_2O_3$ an equation?
a. 3, 2, 1; b. 3, 4, 2; c. 2, 2; d. 2, 2, 1; e. 3, 2

16. Which of the following is NOT a chemical equation?
   a. $3\,CuO + 2\,NH_3 \longrightarrow N_2 + 3\,H_2O + 3\,Cu$
   b. $2\,NaNO_3 \longrightarrow 2\,NaNO_2 + 3\,O_2$
   c. $Cl_2 + H_2O \longrightarrow HClO + HCl$
   d. $2\,SO_2 + O_2 \longrightarrow 2\,SO_3$

17. A word equation contains information about the
a. subscripts; b. charges; c. coefficients; d. reactants.

18. The sum of the coefficients of the equation,

$$2\ BaO_2 \longrightarrow 2\ BaO + O_2 \text{ is}$$

a. 4; b. 5; c. 7; d. 8.

19. The formula, O_2, stands for a MOLECULE of oxygen.
a. true; b. false

20. The use of gumdrops and toothpicks or spheres and connectors to picture a reaction expression is best described as
a. modeling; b. balancing; c. classifying.

21. Which element is not balanced in the following chemical expression?

$$CuO + 2\ NH_3 \longrightarrow N_2 + 3\ H_2O + Cu$$

a. Cu; b. O; c. N; d. H

22. Choose the FALSE statement about diatomic elements.
a. They form molecules.
b. They contain two atoms per formula unit.
c. Some exist as gases at room temperature.
d. They occupy the column at the extreme right of the periodic table.

23. Which of the following is not the correct formula for the element at room temperature?
a. Na; b. F; c. Xe; d. Cl_2

24. To write a reaction expression as a chemical equation, you may have to change a(n)
a. subscript; b. superscript; c. coefficient; d. electron number.

25. All of the following formulas contain polyatomic ions EXCEPT
a. NH_4F; b. Al_2O_3; c. $Mg(OH)_2$; d. $NaNO_3$.

Check the expressions in questions 26-29 to see whether they are equations. Show your work.

26. $CH_4 + 2\ O_2 \longrightarrow CO_2 + H_2O$

27. $N_2 + O_2 \longrightarrow 2\ NO$

28. $MnO_2 + 4\ HCl \longrightarrow Cl_2 + MnCl_2 + 2\ H_2O$

29. $MgCl_2 + NaOH \longrightarrow Mg(OH)_2 + NaCl$

*30. Select the choice from the following which best shows the product(s) of the single displacement reaction, $A + BC \longrightarrow$? .

a. A + B + C
b. A + CB
c. AC + B
d. ABC

*31. Write the formula for the stable ionic compound formed between each of the elements below. (Hint: The combination may not form an ionic compound.)
a. calcium and chlorine
b. fluorine and oxygen
c. sulfur and potassium
d. sodium and iodine

*32. Write the formulas for the compounds of the following.

a. Mg^{2+} and S^{2-}

b. Al^{3+} and CO_3^{2-}

c. potassium ion and hydroxide ion

d. ammonium ion and sulfur ion

e. Sr^{2+} and N^{3-}

For Items 33 to 35, select the best choice.

*33. How many O_2 are needed to make this expression an equation?

$$12\ CO_2 + 6\ H_2O \longrightarrow 2\ C_6H_6 + ?\ O_2$$

*34. In the equation, $H_2SO_4 + 2\ NaOH \longrightarrow Na_2SO_4 + H_2O$, the coefficient which should be used with water is

a. 1; b. 2; c. 3; d. 4.

*35. To balance the expression $CaCl_2 + Na_2SO_4 \longrightarrow CaSO_4 + NaCl$, a coefficient must be used for

a. $CaCl_2$; b. Na_2SO_4; c. $CaSO_4$; d. NaCl.

*36. Balance the reaction expression in item 26.

*37. Balance the reaction expression in item 29.

8 THE BURSTING ATOM

Section 8.1 THE NUCLEUS CAN CHANGE!

8.1 A THE DAY THE WORLD CHANGED

The most dramatic, most terrifying, most impressive happening of the twentieth century occurred over Hiroshima (hirr-OSH-uh-muh) in 1945. An atomic bomb fell onto the city with devastating and instantaneous loss of life.

Science has indeed changed life in this century. It has prolonged life, increased good health, and developed delicate surgery to save lives and remove disfigurement. It has led to rapid communications around the world and to the vast television, movie, and radio entertainment world. It has made possible the increasing variety of foods we can eat. It has produced long-lasting clothing in every texture possible as well as electronic devices such as clocks, television games, and calculators. It has developed computers to take over complex and time-consuming jobs and to open up new powers to humanity. Because of medical discoveries, the population of the world has greatly increased. Scientific discoveries have also increased farm yields making it possible to feed the huge population. Science has altered the way warfare is conducted.

All of these products have changed the way we live, what we know about our universe, how we conduct our government, and even some of our philosophies of life. Nothing brought this to our attention more drastically than the bomb that fell on Hiroshima.

How our society handles each change which science brings is the responsibility of every citizen in it. This is your task. This is the big reason why you study science, to make wise decisions when it is your turn to do so. And it will be your turn soon!

8.1 B SOME NUCLEI CAN CHANGE

The atom bomb was an outcome of the discovery that the nucleus of the atom can change and is changing naturally in certain elements. What a surprise that was to the scientific community! Up till then, they had believed that the nucleus never undergoes change. Once gold, always gold, or once nitrogen, forever nitrogen, was what they believed.

Today, we know that although nuclear change does not occur in chemical reactions (those changes have to do only with the electrons outside the nucleus), it does occur in certain atoms SPONTANEOUSLY (sponn-TAY-nee-us-lee), that is, by itself without any outside help. Nuclear changes can also be caused by tremendously powerful impacts from other atomic or subatomic particles.

8.1 C NUCLEAR CHANGE

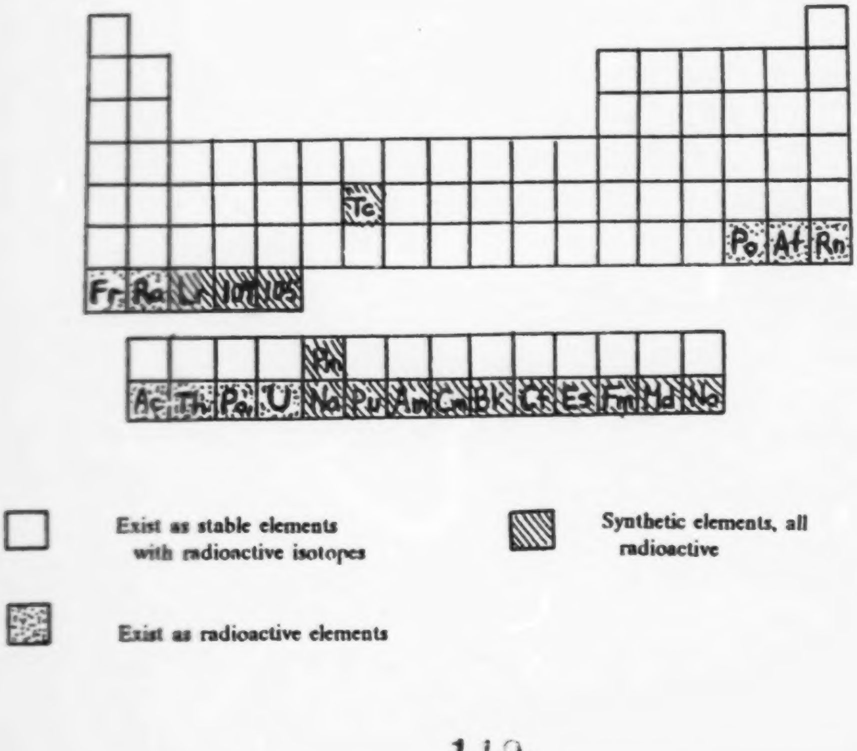
There are two main classes of nuclear change.

(1) Radioactivity

RADIOACTIVITY is the name for the process by which atoms spontaneously emit bits of the nucleus.
RADIOACTIVE DECAY is another name for radioactivity.

Radioactive decay takes place independently of practically anything going on outside of the nucleus. Reacting a radioactive element with chemicals, pasteurizing it or boiling it, freezing or compressing it, or any other kind of chemical or simple physical change does not affect the radioactive changes which take place in the nucleus. Some types of radioactive change take place rapidly, others slowly, but they all proceed without regard to what's going on outside.

Table 8.1 RADIOACTIVITY IN THE PERIODIC TABLE


Tc
Po
At
Rn
Fr
Ra
Lr
Pm
Ac
Th
Pa
U
Np
Pu
Am
Cm
Bk
Cf
Es
Fm
Md
No
Exist as stable elements with radioactive isotopes
Synthetic elements, all radioactive
Exist as radioactive elements

When an atom emits particles from the nucleus, the identity of the atom changes.

Only a few elements (see Table 8.1) with unstable nuclei exist in nature at this time. The process by which they decay is called ***natural radioactivity.***

(2) Changes due to nuclear collisions

Bombardment of atoms by high energy neutrons can cause a heavy atom to split into two or more lighter nuclei.

When a heavy atom is split by impact of another particle into two or more nuclei, the process is called ***FISSION.***

Small atoms can also be smashed into each other so that they combine.

FUSION *takes place when nuclei combine to form a nucleus of higher atomic number.*

Fusion has been accomplished by speeding up small particles to tremendous speeds and then slamming them at other small particles.

The products of fission or fusion may themselves be radioactive.

In the periodic table, technetium (number 43), promethium (number 61), and the elements from neptunium (number 93) and up are synthetic and radioactive: that is, these radioactive elements have been made in laboratories or nuclear energy plants and are not found in nature. The process by which these synthetic elements decay is called ***artificial radioactivity.****

Exercise 8.1

8-1 Distinguish between each of the following: a) spontaneous nuclear change, b) radioactivity, c) radioactive decay, d) fusion, e) fission, f) natural radioactivity, g) artificial radioactivity.

8-2 Distinguish between chemical change and radioactive change.

Section 8.2 DISCOVERY OF RADIOACTIVITY

For centuries, people used to wonder what fuels the sun. How can such tremendous fires take place without having used up all the fuel ages ago? No one suspected that it was a nuclear fire.

The first clue was discovered in 1896 by Henri Becquerel (Ahn-REE Beck-RELL), a Frenchman, when he was studying certain fluorescing (flew-or-ESS-ing) minerals. These minerals glow when exposed to strong light and continue to glow for a while even when taken into a dark room.

Becquerel thought that fluorescence might be related to the newly discovered X-rays. He wrapped photographic film in a black cover. Then, he placed a fluorescing mineral on top of it and planned to expose it to sunlight. If the fluorescent rays were X-rays, they should pass right through the black cover and expose the film.

Several cloudy days passed with no sunshine available to irradiate the mineral so Becquerel put the samples and film away in a drawer. He was a careful worker and always checked the film before use. To his surprise when he went to use it again, the film in the drawer was fogged as if it had been strongly exposed to light.

Becquerel repeated the experiment, again without allowing sunlight to fall on the mineral. The radiation that fogged the film had nothing to do with fluorescence or sunlight. It was coming from the mineral itself! We now know that the mineral contained radioactive uranium. The uranium, as it decayed, gave off rays which affected the photographic chemicals.

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*About 1500 isotopes (see p. 113) are known. Less than 300 are stable.

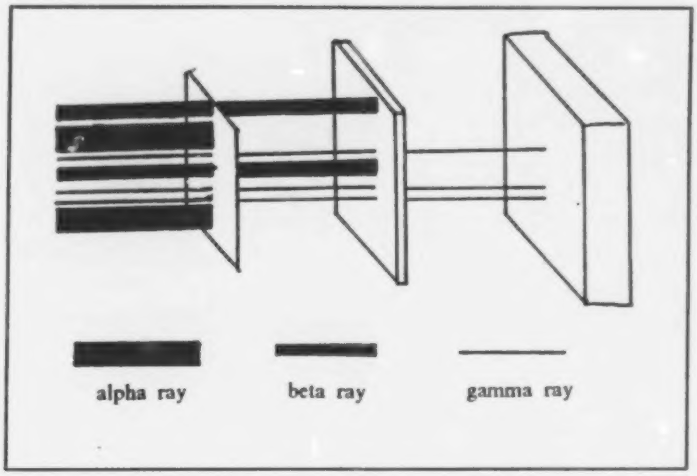
Becquerel studied the mineral and its emissions. He assigned his student, Marie Sklodowska (1867-1934), to study pitchblende, a uranium ore with unusually high emissions. She was in Paris working toward her doctorate in mathematics and physics. While continuing her work, Sklodowska married Pierre Curie, a well-known French physicist and they worked on it together. The Curies isolated uranium, radium and polonium from the ore. It was Marie Curie who named the process by the name of radioactivity.

Marie Curie, Pierre Curie, and Henri Becquerel were jointly awarded the Nobel Prize for Chemistry in 1903. Pierre Curie was killed in the street by a horse and carriage accident three years later. Marie continued her pioneering work and became the first person to win two Nobel prizes. She died of pernicious anemia probably brought on by long exposure to radioactive radiation.

Exercise 8.2

8-3 Name the three discoverers of radioactivity.

Section 8.3 RADIOACTIVE DECAY



Ernest Rutherford was digging potatoes on his father's farm in New Zealand when he learned of his scholarship to Cambridge University. He promptly threw down his hoe, exclaimed, "That's the last potato I'll dig," and caught a ship for England. There, he carried out research on radioactivity.

In 1899, Rutherford showed that there were two different types of rays emitted by the nuclei of the radioactive substances; he named them alpha rays and beta rays. Soon after, a third type called the gamma ray was discovered.

Alpha and beta rays consist of speeding particles.

ALPHA RAYS *are fast-moving helium particles stripped of electrons,* He^{2+}.

BETA RAYS *are high energy electrons formed during decay.*

GAMMA RAYS *are an extremely high energy form of invisible light.*

The table following summarizes these rays and the extent to which they penetrate matter.

Table 8.2 Characteristics of Radioactive Rays

Ray	Symbol	Description	Blocked by
alpha ray	α	helium nucleus (He^{2+})	paper
beta ray	β	electron (e or e^-)	metal sheet
gamma ray	γ	light energy	thick lead or several feet of concrete

Exercise 8.3

8-4 What is an alpha ray? a beta ray? a gamma ray?

(Exercise 8.3 is continued on the next page)

8-5 How can alpha rays be blocked? Beta rays? Gamma rays?

8-6 a. What would happen if you placed radioactive uranium on a wrapped package of Polaroid film?

b. Which rays would be involved?

8-7 What kind of a shelter would make you safe from radioactive rays?

Section 8.4 RADIOACTIVE ISOTOPES

8.4 A MASS NUMBER

At least one (and often more) of the isotopes of every element is radioactive. Some isotopes change very rapidly while other isotopes of the same element may decay very slowly. In discussing the radioactivity of an element, it is important to be able to identify the radioactive isotopes.

The MASS NUMBER is the sum of the numbers of protons and neutrons in an atom.

mass number = number of protons + number of neutrons

For example, an atom of plutonium with 94 protons and 148 neutrons has a mass number of 242: **94 + 148 = 242.**

Isotopes may be identified by writing the name of the element followed by a hyphen and the mass number. Thus, the isotope of carbon with six protons and six neutrons is written as carbon-12 while the isotope of carbon with six protons and eight neutrons is shown as carbon-14.

Exercise 8.4 A

8-8 a. What is the mass number of an atom of platinum with 78 protons and 117 neutrons?

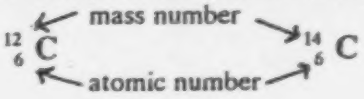
b. Write an identifying name for this isotope.

8-9 a. What is the mass number of an atom of barium with an atomic number of 56 and with 81 neutrons?

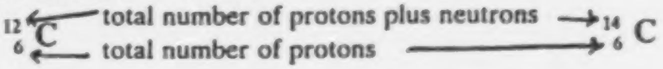
b. Write an identifying name for this isotope.

8.4 B SYMBOLS FOR ISOTOPES

Symbols may also be used to identify isotopes especially in equations for nuclear changes. The symbol C, by itself, stands for the natural mixture of isotopes of carbon. Below are symbols for two of the isotopes of carbon, one with 6 neutrons and one with 8 neutrons.



Notice that the labels could also be shown as



Exercise 8.4 B

8-10 Given the symbol $^{77}_{33}As$,

a. how many protons does each atom have?

b. what is the mass number?

c. how many protons and neutrons does an atom have all together?

(Exercise 8.4 B is continued on the next page)

8-11 Given the symbol, $^{37}_{17}X$,
  a. how many protons and neutrons does it have in all?
  b. What is the real symbol for the element described as "X"?

8-12 What is the nuclear symbol for germanium-73?

Optional 8.4 C CALCULATION OF NEUTRONS FROM THE NUCLEAR SYMBOL

Since mass number = number of neutrons + number of protons,
then number of neutrons = mass number - number of protons.

The number of neutrons in $^{12}_{6}C$ is 12 - 6 = 6.

The number of neutrons in $^{14}_{6}C$ is 14 - 6 = 8.

Exercise 8.4 C

8-13 How many electrons, neutrons, and protons are in a neutral atom of
  a. $^{226}_{88}Ra$; b. $^{23}_{11}Na$; c. $^{235}_{92}U$; d. $^{222}_{86}Rn$

8-14 How many neutrons are in a. ^{90}Sr; b. ^{32}P ?

8-15 a. For which radioactive rays do the following nuclear symbols stand? (1) $^{4}_{2}He$ (2) $^{0}_{-1}e$
  b. Why is there no nuclear symbol for the gamma ray?

Section 8.5 RADIOACTIVE HALF-LIFE AND DATING

8.5 A HALF-LIFE

An element which undergoes radioactive decay usually undergoes a change in identity. For example, uranium-238 loses a helium particle; since it has lost two protons and two neutrons, it has a new atomic number and mass. The new element formed is thorium-234 which is itself radioactive.

Not all of the atoms of a radioactive element decay at one time. For some elements, only a few atoms out of every hundred decay in a day or month or even a year. It may take a very long time for a sample of this element to show much change. For other elements, a few atoms out of every hundred may decay every minute so that the change quickly becomes evident. Which particular atoms decay cannot be predicted but each element decays steadily at its own rate.

*The **HALF-LIFE** is the time it takes for one-half of a sample of radioactive matter to decay.*

The half-life of an isotope is a property which differs for each isotope (but does not depend on the size of the sample). Half-lives vary from seconds to billions of years depending upon the isotope. Radioactive materials with a very short half-life may completely change to other elements in a few seconds. Those with an extremely long half-life may still exist when the universe dies.

Activity 8.1 DECAYING DISCS

Purpose: to model radioactive decay

Materials: 30 cardboard disks colored differently on each side, aluminum foil pie pan, graph paper and ruler

Procedure:

Year Zero: Obtain the materials.

Year One: Gather the 30 disks into your hands and shake them about. Then, drop them into the pie pan. Call one color "up" and the other "down." If a disk lands up, set it aside for the next year. If a disk lands down, it has decayed and is eliminated from the game. Set up a data table to record the number of disks left in the game (undecayed) each year beginning with Year Zero.

Year Two: Repeat the procedure above using the remaining undecayed disks. Remember to record the disks remaining after this year.

Year Three: Repeat year after year until all the disks have decayed.

Note: it is possible to have no decay in one toss of the disks.

Questions:

Q. 1 Make a graph of the number of remaining (undecayed) disks versus years. Place the number of disks on the vertical axis.

Q. 2 As the time since start increases, what happens to the number of disks remaining? What kind of a relationship is this?

Q. 3 How many years were required to reach the point when only one-half of the disks remained? What is the name of this special time?

Q. 4 Suppose you had started with forty disks. How many years would it take to decrease the number of disks to twenty?

Q. 5 Discuss how this activity models the random nature of radioactive decay.

Exercise 8.5 A

8-16 The half-life of iodine-131 is 8.07 days. How much iodine will be left in an 80 g sample after 8.07 days?

8-17 Uranium-238 has a half-life of 4.5 billion years.

a. Write the nuclear symbol for this isotope.

b. How much uranium is left in 200 g uranium-238 at the end of 4.5 billion years? How much of the sample is something other than uranium?

Optional 8.5 B QUANTITATIVE HALF-LIFE

As an example of half-life, consider the decay of radium-226 to radon-222. In 3.8 days, half of any sample of radium-226 decays to radon-222.

**Q. 1 If 100 g of radium-226 stands around for 3.8 days (one half-life), how much radium-226 and how much radon-222 are present?

**Q. 2 If the 50 g of radium-226 stands around for another 3.8 days, how much radium is left? How much radon has formed from the 100 g of starting material?

Notice that 100 g of radium-226 has 300 thousand billion billion atoms in it. After three half-lives (11.4 days) when only 12½ g of radium-226 are left, there are still

25 thousand billion billion atoms of radium-226!

Since decay is a random process, we can't be sure just when the last atom will depart its identity as radium. It is informative to talk about the half-life of a radioactive material but not about its life.

Exercise 8.5 B

8-18 The half-life of barium-131 is 12.0 days. How much of an 80 g sample will be left after 24.0 days? After 3 half-lives (36 days)?

(Exercise 8.5B is continued on the next page)

8-19 Strontium-90 has a half-life of 28.1 years.

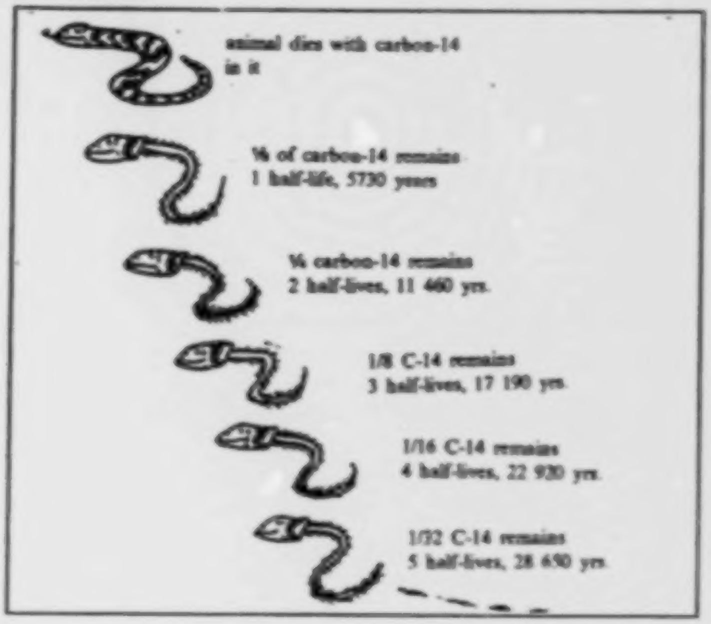
- a. After 56.2 years, how much of it is left?
- b. How long will it take to become 1/8 of what it was at the start?

Answers to Q's

Q. 1 50 g of each are present.

Q. 2 Half of the 50 g of radium-226 will have changed to radon-222. Only 25 g of radium-226 out of the original 100 g will be left and 75 g of radon-222 will have formed.

Optional 8.5 C RADIOACTIVE DATING


animal dies with carbon-14 in it
½ of carbon-14 remains 1 half-life, 5730 years
¼ carbon-14 remains 2 half-lives, 11 460 yrs.
1/8 C-14 remains 3 half-lives, 17 190 yrs.
1/16 C-14 remains 4 half-lives, 22 920 yrs.
1/32 C-14 remains 5 half-lives, 28 650 yrs.

Carbon-14 is one of the elements used in radioactive dating. Carbon-14 is formed from nitrogen in the atmosphere at a fairly constant rate by cosmic radiation in our atmosphere. (Cosmic rays are high speed nuclear particles from outer space.)

Plants constantly take in carbon dioxide with some carbon-14 in it. Animals eat plants. After the plant or animal dies, no more carbon-14 enters it. Carbon-14, with a half-life of 5730 years, slowly decays to carbon-12. The time since a tree was cut or flax harvested to make cloth or the time since an animal died can be calculated from the ratio of carbon-14 to carbon-12. The ratio steadily decreases. It was radiocarbon dating which established the age of the Dead Sea scrolls discovered in 1947 as about 1900 years.

The half-life can also be used to measure the age of substances in rocks. Molten material formed in nature solidifies to rock. As radioactive materials in the rock decay, their decay products remain trapped in the rock. Uranium-238 decays to lead-206. The ratio of lead-206 to uranium-238 in a rock gives an idea of its age. The ages of ancient rocks by this method range from 3 to 4.5 billion years. This suggests that the age of the earth cannot be less than that.

Exercise 8.5 C

8-20 How does the ratio of one isotope to another in a plant fossil give an idea of its age?

8-21 An ancient rock is opened and a bit of it is analyzed for its lead-206 and uranium-238 content. How does this reveal the age of the rock?

Section 8.6 NUCLEAR FUSION AND FISSION EACH PRODUCE ENERGY

When light nuclei combine (fusion) or heavy nuclei are split apart by impact of a particle (fission), mass is changed into energy. It was Einstein who predicted this effect.* Einstein stated that mass could be converted to energy and vice versa.

Fusion and fission both involve a loss of mass. The lost mass is converted into energy. The quantities of energy produced by nuclear change are more than a million times greater than those produced by chemical change.

Equations may be written for radioactive changes using . the symbols for atomic isotopes. The equation may just show one element splitting (radioactive decay) or it may show an atom being impacted by a nuclear particle (fusion) or it may show two atoms combining on impact (fusion), as in the following.

a. ${}^{238}_{92}U \longrightarrow {}^{4}_{2}He + {}^{234}_{90}Th$ Radioactive decay

b. ${}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}p$ Fusion

c. $2\,{}^{12}_{6}C \longrightarrow {}^{24}_{12}Mg$ Fission

Exercise 8.6

8-22 Compare the energies produced in a nuclear reaction and in a chemical reaction.

8-23 a. What is converted to energy in a nuclear reaction?
b. Is energy produced by natural radioactivity?

8-24 Identify each of the following reactions as radioactive decay, fission, or fusion.

a. ${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$

b. ${}^{239}_{94}Pu + {}^{1}_{0}n \longrightarrow {}^{90}_{38}Sr + {}^{147}_{56}Ba + 3\,{}^{1}_{0}n$

c. ${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$

Section 8.7 NUCLEAR FISSION

8.7 A WE CAN MAKE GOLD!

Before modern chemistry began, the ancient alchemists tried to make gold from cheaper metals but they never succeeded. There was no way that they could succeed because they were trying to make the gold by chemical change. We know now that the identity of an element does not change during a chemical reaction.

The alchemist's dream has been realized, at long last. Fission occurs when the nucleus of a heavy atom is split by bombarding it with atomic or subatomic particles. The linear accelerator at the Lawrence Berkeley Laboratory in California used very fast-moving ions of low mass to knock nuclear fragments out of bismuth-83. The product was gold-79! The alchemists would definitely not have been satisfied with this process for making gold. It cost $10 000 to produce gold worth less than one billionth of one cent.

8.7 B WE CAN MAKE ATOMIC BOMBS!

Isotopes of the heavy elements may undergo fission when hit by neutrons of sufficient energy. Neutrons fired at uranium-235 split it up to produce two lighter elements, several neutrons, and a large quantity of energy. The reaction, in words, is as follows. (The reaction using nuclear symbols is also shown for reference as needed.)

uranium-235 + 1 neutron ⟶ krypton-92 + barium-141 + 3 neutrons + energy.

$${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{92}_{36}Kr + {}^{141}_{56}Ba + 3\,{}^{1}_{0}n + \text{energy}$$

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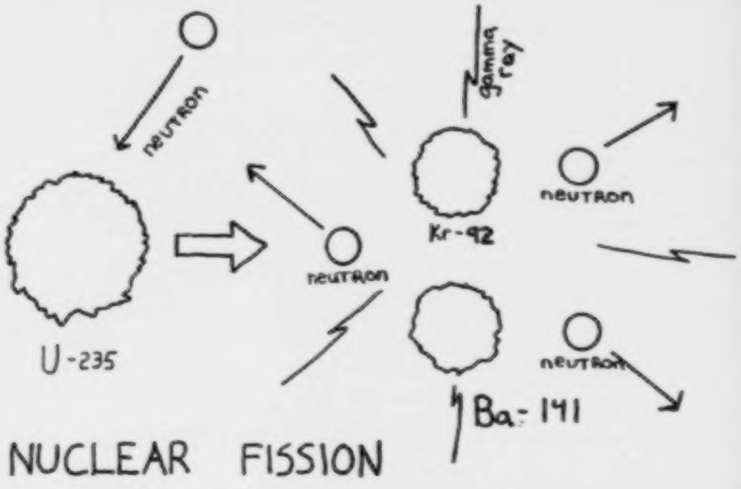
[*] Einstein stated the relationship between mass and energy in his famous equation, $E = mc^2$, where m stands for the rest mass of an object and c for the speed of light. According to this equation, mass is a form of energy.

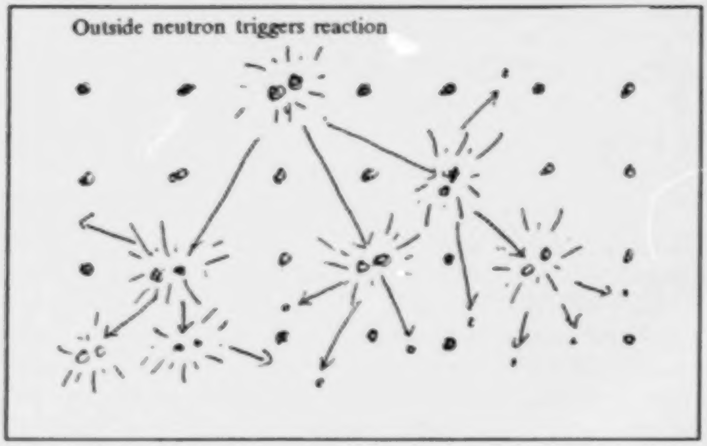


This reaction produces about 26 million times as much energy as do your gas burners. The reaction shown here is one of many different fission reactions that U-235 undergoes when bombarded by neutrons.

The fission of uranium-235 is of special interest because more neutrons are produced than are used. Some of the neutrons produced have a good chance of hitting another uranium-235 atom if there are enough atoms nearby. Then, another uranium-235 atom splits and more neutrons are produced. If there is enough uranium-235 in a clump, many of the neutrons can't get away without splitting more and more uranium atoms. A chain reaction takes place. We have a nuclear explosion! An atom bomb!

Chain reactions occur (1) when more neutrons are produced than are used, and (2) there is enough mass involved so that the new neutrons are very likely to hit more fissionable nuclei.

The minimum mass that has to be brought together for a chain reaction to occur is called the ***CRITICAL MASS*** .



Many of the products of fusion reactions are themselves radioactive. As a result, a fission bomb spews radioactive materials and rays into the air, contaminating the atmosphere for long periods after the bomb explosion itself.

Exercise 8.7

8-25 What is a nuclear chain reaction?

8-26 For a chain reaction, how must the number of neutrons produced compare to the number reacting?

8-27 What is the meaning of "critical mass" in a chain reaction?

8-28 How are elements created in the laboratory?

Section 8.8 NUCLEAR FUSION

The sun's tremendous energies and those of other stars come not from burning fuel but from fusion-powered reactions. The energy is released in a series of reactions in which lighter nuclei fuse together to form heavier, more stable nuclei. The first steps result in the fusion of hydrogen to helium, the process that supplies most of the sun's energy today. As the sun becomes older, other fusion reactions will take place.

Fusion reactions yield approximately ten times as much energy per gram of fuel as the fission process. Better yet, the products formed are not radioactive; there is no problem with environmental contamination. Unfortunately, scientists have not yet been able to sustain a fusion reaction for more than a tiny period of time.

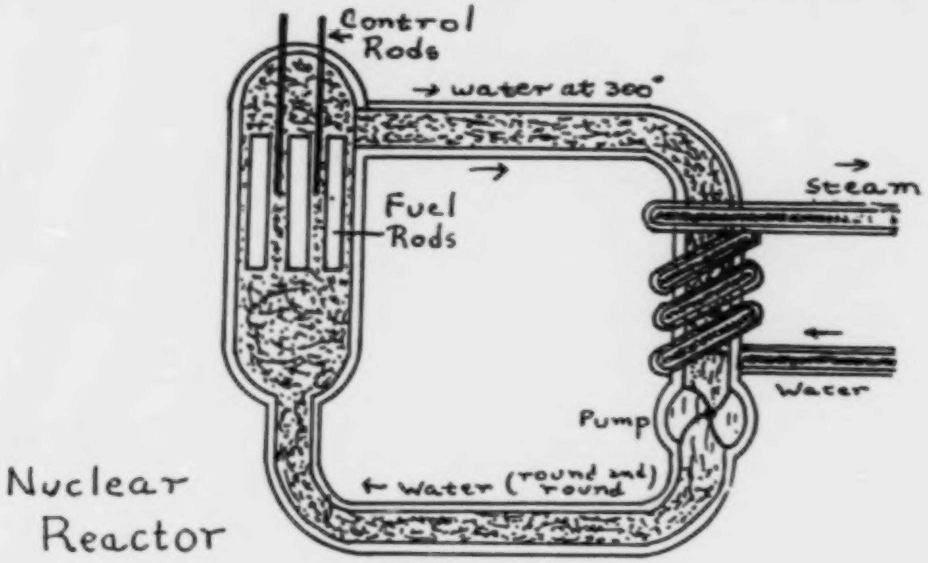
Exercise 8.8

8-29 What elements are used and produced in the nuclear reaction which takes place in our sun? Is it fission or fusion?

Section 8.9 USES OF NUCLEAR CHANGE

8.9 A NUCLEAR REACTORS

Nuclear reactors use fission chain reactions that produce enormous quantities of heat. The heat is used to convert water to steam to drive a turbogenerator which produces electricity. Up to 10% of the electrical energy in the United States is produced by reactors.



In nuclear reactors, the heat energy produced by uranium-235 warms water which circulates around the reactor. Completely separate pipes are set around and through this system with water running through them; this is the heat exchanger. The water in the heat exchanger absorbs the heat from the reactor water and exits to the electricity generator as steam.

To control the rate of the reaction to keep the chain reaction from speeding up explosively, control rods are used. These control rods are made of a material such as cadmium which is a good absorber of neutrons. To slow down or to speed up the reaction, the control rods are moved up and away from or down and closer to the fuel rods.

All labor in a reaction chamber is carried out by remote control because it is *hot*. *Hot*, in this case, refers to dangerous rays rather than to heat.

Nuclear reactors are very helpful for the nation's energy supply. But they also introduce hazards. Nuclear reactors produce radioactive wastes as side products of the reaction. Also, the used fuel rods, control rods, and reactor parts become radioactive waste. These wastes must be removed to safe locations. Safe locations are difficult to find and the problem continues to be vexing.

Nuclear reactors also need careful supervision, inspection, and a program of repairs and replacements to make sure that the chain reaction does not speed up to where it can become a nuclear explosion. The Three Mile Island reactor in Pennsylvania in 1979 and the Chernobyl reactor in 1986 have both suffered serious accidents, and the radioactive damage done to people by the Chernobyl disaster is still developing.

Should scientists produce a large-scale nuclear fusion reaction, reactors will be safer to use because fusion is a clean process; radioactive products are not produced.

Exercise 8.9 A

8-30 What do the control rods do in a nuclear reactor?

8-31 How is steam produced by a nuclear reactor without having it contaminated by radioactivity?

8-32 Why do we feel it necessary to look for alternative fuels instead of nuclear materials to use as a source of energy?

8-33 Why would nuclear fusion reactors be preferable to nuclear fission reactors?

8.9 B OTHER USES OF RADIOACTIVITY

Radiocarbon dating, as discussed in Section 8.5 C, can be used to measure the age of fossils, ancient stones, and certain antique objects.

An important use of nuclear material is the use of radiotracers for research in medicine and biochemistry.

> ***RADIOTRACERS** are molecules used in chemical research in which one of the atoms has been replaced by a radioactive atom.*

The radiotracer acts as a tag to allow the pathway of a molecule and its chemical reactions to be traced through the body in the laboratory. Radioactive tracers have been used to learn about biological processes, to diagnose disease and heart damage, and to monitor drugs in the body.

High energy radiation by cobalt-60 or other radioactive material is used to kill cancerous tissue. Controlled exposures are needed because the radiation also damages healthy tissue, although less rapidly.

Nuclear radiation is now being used for pest control. The screwworm fly is a persistent cause of infection in cattle. Worms of one sex are irradiated to become sterile. The screwworm population can be nearly eradicated in one generation.

Exercise 8.9 B

8-34 Name three uses of radioactivity other than to produce energy.

Section 8.10 EFFECTS OF RADIATION

8.10 A RADIATION MEASUREMENT

Levels of radioactivity can be measured by a Geiger counter. The counter emits sound clicks or light flashes when radioactive atoms pass through it; the more clicks per second, the greater the radioactivity. Johannes Geiger was Rutherford's assistant at Cambridge University. Rutherford, a very impatient man, needed someone to carefully count the individual clicks given off by a device that sensed radioactive rays. The modern Geiger Counter was named in Geiger's honor because he had the skill and patience to do this work.

Photographic paper inside of badges (recall Becquerel's experiment) is used to record the level of radiation that a person has received over a period of time.

8.10 B EFFECTS OF RADIATION ON THE BODY

Exposure to radiation which is severe can damage the body fatally. However, the body can recover from a minor short exposure because the body rids itself of cells all the time and builds new ones. If the small doses are repeated too often, the body cannot repair itself in time. Cancer has been appeared many years after the initial exposure to repeated small doses of radiation. Hence, it is important to keep track of and to restrict radiation over a period of time.

Rapidly dividing reproductive cells of unborn babies are especially susceptible to radioactive damage. Not only can radiation cause damage and cancer in our bodies but it can also affect the genes so as to threaten future generations.

There are three factors which affect the extent of the damage:

(1) quantity of radiation,
(2) type of radiation,
(3) material through which it passes.

The quantity of radiation is expressed as energy per mass of body tissue. The type includes whether the radiation is alpha, beta, or gamma, or X-ray radiation, or high energy neutrons. Although alpha radiation has a much lower penetration than the other rays, it has great ionizing power in the tissue through which it passes. A dose of alpha radiation or of high energy neutrons can be ten times more toxic than the other types. Note that different bones and organs of the body may be affected differently by the same radiation. The unit of radiation, based on the biological effect of the dose of radiation, is the **R E M** (roentgen equivalent in man). Other units of radiation such as the *curie* and *rad* are also in use.

8.10 C SOURCES OF RADIATION

The quantity of radiation you receive depends on where you live and your life style. Table 8.3 and Activity 8.2 will give you an idea of the sources and effects of radiation.

Table 8.3 Effects of a Short-Term Dose of Radiation

Dose (rems)	Damage Produced
0-25	not detectable
25-50	white blood count decreases temporarily
50 to 100	big drop in white blood cell count
100 up to 500	nausea, hair loss, bleeding, ulcers, possibly fatal
500	half of exposed population dies within 30 days

Exercise 8.10

8-35 Name two devices to measure the level of radiation exposure.

8-36 Which inflicts more damage, high energy neutrons for five seconds or the same dosage of gamma rays for ten seconds?

8-37 The average yearly radiation dosage is 360 mrem/year. If received in a single dose, such radiation is harmful. Why aren't we all showing the harmful effects of the radiation?

*Activity 8.2 YOUR PERSONAL RADIATION EXPOSURE COUNT

Purpose: to calculate how much radiation you receive per year
Materials: chart following

Procedure: Complete a copy of the chart below to calculate how many millirems of exposure to radiation you receive per year. The figures filled in for you are average for the population of the United States.

PERSONAL EXPOSURE CHART

Source	Exposure in mrem/year
1. Natural radiation	
a. From the earth	47
b. Add 1 for each additional 100 yards above sea level	______
c. From cosmic radiation	26
d. Add 1 for each 1500 miles flown in a jet	______
e. Inhalation of air (from radon)	200
f. In human tissues (mostly potassium-40)	40
Total	______
2. Human-produced radiation	
a. Building materials	7
b. X-ray diagnosis, each one chest, add 40	______
intestinal, add 40	______
dental, add 10	______
c. Nuclear power industry	0.1
d. TV tubes, industrial wastes	1
e. Radioactive fallout	1
Total	______
Grand total	______

Your teacher will help you to collect the radiation dosage of the other members of your class.

Questions

Q. 1 What are the natural sources of radiation?
Q. 2 What are the human-produced sources of radiation?
Q. 3 What is the largest single source of natural radiation?
Q. 4 What is the biggest source of human-produced radiation?
Q. 5 How does your annual radiation dosage compare to that calculated by your classmates?
Q. 6 Why do the values differ within your class?
Q. 7 How can you reduce your radiation intake?
Q. 8 How does your value compare to the average American dosage of 360 mrem/year?

Section 8.11 RADON

Activity 8.2 presents the common sources of radiation to which you might be exposed. Part of the radiation is from the background radiation, that is, radiation present in the air and ground about you. About half of the background radiation comes from radon which penetrates homes from the ground beneath.

Radon-222 is an invisible, radioactive gas formed in most rocks and soils. Radon-222 is itself harmless and unreactive. However, it decays to form radioactive products which can cause lung cancer when inhaled due to alpha ray emission.

Outdoors, radon is always present in the air but in quantities too small to affect health. Indoors, radon can accumulate in some houses to dangerous levels. Unfortunately, its presence cannot be accurately predicted from the local geology. Sometimes, one house has an unacceptable radon concentration while the house right next to it is safe.

Do-it-yourself kits are available for radon testing. Each house should be tested for it. Radon enters the house through cracks in foundations, openings around sump pumps, and drains. If the radon level is too high, these entries can be found and sealed. Where necessary, a system to ventilate the soil under the foundation can be installed.

Exercise 8.11

8-38 Why is radon from the earth harmful in homes but not outdoors?

8-39 What actions can be taken to make homes safe from radon?

Section 8.12 WHAT CAN WE DO ABOUT RADIATION?

Currently, we know little about the effect of long-term exposure to low levels of radiation from radon, radioactive rays, X-rays, and other sources. It makes good sense to minimize exposure wherever possible.

We need to select geologically sound sites for reactor power plants, and to find safe methods and safe sites for waste disposal. At the same time, we need to continue to search for better methods to produce nuclear energy, and to find other sources of energy. Fusion energy is an especially attractive goal because it does not produce radioactive waste products.

AS CITIZENS, YOU WILL NEED TO BE AS KNOWLEDGEABLE AS POSSIBLE ABOUT SCIENCE SO THAT YOU CAN HELP TO MAKE WISE DECISIONS IN THE FUTURE.

* * *

Chapter 8 Review

Vocabulary

Use each of the vocabulary words below only once to complete sentences 1 through 15 below and on the next page.

Radioactivity
Particle Impacts
Radon
Radiotracers
Half-life
Nuclear Reactor
Alpha Rays
Rutherford
Radioactive Decay
Becquerel, M. Curie, P. Curie
Mass Number
Geiger
Chain Reaction
Beta Rays
Gamma Rays

1. This natural element, ________________________, can accumulate in the home from the ground and cause radiation damage.

2. The process whereby particles and/or energy are spontaneously emitted from a nucleus is called ________________________.

3. Unstable isotopes may undergo ________________________ .

4. A(n)________________________ creates serious waste disposal problems.

5. Biochemists use tagged molecules as ________________________ to study chemical pathways.

6. A radioactive sensing instrument received its name from ________________________ .

7. These radioactive rays have no mass: ________________________ .

8. When more neutrons are produced than used in the presence of sufficient mass, a ________________________ may take place.

9. When heavy atoms are subjected to ________________________ , nuclear fission can occur.

10. ________________________ is a property of a radioactive substance which is unique to it.

11. The sum of the neutrons and protons in a nucleus is the ________________________ of an isotope.

12. Natural radioactivity was discovered by ________________________ .

13. ________________________ are made up of negative particles.

14. ________________________ are positive.

15. ________________________ named the radioactive rays.

Applications

1. How does the reaction of uranium to form uranium oxide differ from the decay of uranium-235?

2. Explain the difference between the classifications of the following.

   a. $2\ H_2 + O_2 \longrightarrow 2\ H_2O$

   b. ${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{3}_{2}He$

3. Susan was interested in the pathway taken by fertilizer as it enters a plant. She obtained some photographic film and radioactive phosphate fertilizer. Briefly, help her design an experiment to determine which parts of the plant concentrate the fertilizer.

4. Three samples of material placed on a piece of photographic film reacted in the following manner. Compound AB left a foggy spot on the film; compound AC produced no fog; and compound BC fogged the film. Which element, A, B, or C could be uranium-235? Explain your answer for credit.

5. Would you expect alpha, beta, or gamma radiation to be attracted toward a negatively charged plate? Explain.

6. Name three basic differences between chemical and radioactive changes.

7. Is the reaction below fission or fusion? Explain.

$${}^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}H$$

8. Is the reaction below fission or fusion? Explain.

$${}^{1}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He$$

9. What devices are used to detect radiation?

10. Which ray from radioactive decay has the greatest penetrating power?

Choose the phrase or word which best completes each question below.

11. An isotope of bromine has the nuclear symbol ${}^{87}_{35}Br$. It has
a. 35 protons and 76 neutrons.
b. 76 protons and 35 neutrons.
c. 35 protons and 87 protons plus neutrons.
d. 35 protons and 122 protons plus neutrons.

12. When an atomic nucleus spits into two or more smaller nuclei, the process is called
a. explosive.
b. fusion.
c. burning.
d. fission.

13. The kind of pollution attributed to nuclear power plants is
    a. smog.
    b. acid rain.
    c. dangerous waste.
    d. sulfur dioxide.

14. Which of the following is the least penetrating type of radiation?
    a. alpha; b. beta; c. gamma

15. What kind of radiation is a ray of helium nuclei?
    a. alpha; b. beta; c. gamma

16. A type of radiation that has no mass or charge is
    a. gamma; b. beta; c. proton; d. alpha.

17. Chain reactions are possible because
    a. the number of neutrons produced is greater than the number used.
    b. mass is changed into energy.
    c. the reactions give off heat.
    d. there isn't too much critical mass.

18. The discovery of radioactivity was initiated by
    a. the Curies. c. Geiger.
    b. Rutherford. d. Becquerel.

19. Radioactivity cannot be used to
    a. estimate the age of objects. c. destroy agricultural pests.
    b. cool nuclear reactors. d. diagnose diseases.

20. The half-life of an element
    a. is short; b. is long; c. is constant; d. decreases with time.

21. Which is false about radioactivity?
    a. It is produced only in nuclear reactors.
    b. It produces energy.
    c. It occurs randomly.
    d. It involves nuclear fission.

22. The half-life of a radioactive substance is
    a. half the life-span of the substance.
    b. usually fifty years.
    c. the time for radium to change to lead.
    d. found from Einstein's equation.
    e. the time for half of the material to decay.

23. A measurement unit which measures radiation exposure is the
    a. hertz; b. rem; c. joule; d. counter.

24. Which of the following does not describe nuclear fission?
    a. production of energy c. loss of mass
    b. nuclear change d. joining of nuclei

25. A beta ray will be stopped by
    a. lead shield.
    b. sheet of paper.
    c. sheet of metal.
    d. both a and c.

26. Carbon dating would not be useful to estimate the age of
    a. a cotton scarf that belonged to an Egyptian queen.
    b. a lock of Columbus's hair.
    c. a caveman's leather thong.
    d. your pet goldfish.

27. Which of the following activities would be likely to MOST increase your exposure to radiation?
    a. fly to France   c. visit a nuclear energy plant
    b. get a chest X-ray   d. listen to a hard rock band

28. The energy produced from fission in a nuclear energy plant is in the form of
    a. electricity.   c. magnetism.
    b. heat.   d. work.

29. We are currently exposed to more radioactivity around us from fallout than in our own human tissues.
    a. true;   b. false

30. The major source of radon which is in the air comes from
    a. the earth beneath.
    b. nuclear energy
    c. cosmic rays.
    d. radioactive fallout.

31. The heat and light of the sun are produced by (select the best choice)
    a. fusion.
    b. fission.
    c. burning.
    d. radioactive decay.

*32. Complete the following table.

element	atomic number	number of protons	number of neutrons	mass number
Polonium	84		126	
Radon		86		222
	58			140
			74	127

*33. An isotope of osmium has the nuclear symbol ${}^{191}_{76}Os$. It has
   a. 76 protons and a mass number of 191.
   b. 76 neutrons and 191 protons.
   c. 76 protons and 191 neutrons.
   d. 76 protons and a mass number of 247.

*34. The half-life of Cs-137 is 30 years. How much of a 120 g sample would remain after 90 years?

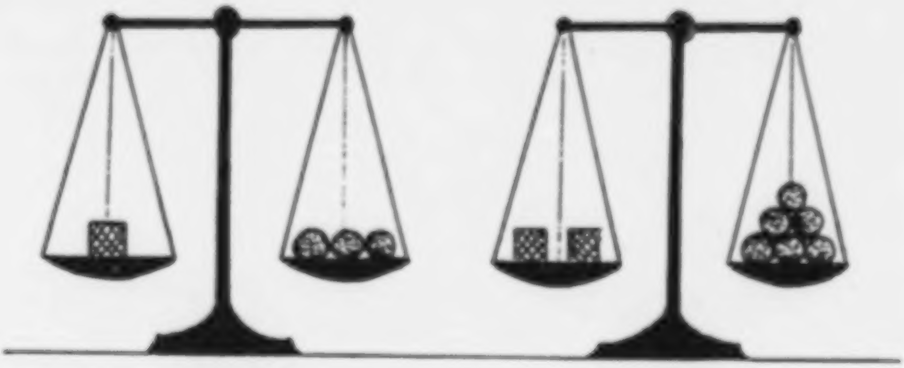
*35. The number of neutrons in the nucleus of ${}^{37}_{17}Cl$ is
   a. 17; b. 37; c. 20; d. 54.

*36. An isotope of curium has the nuclear symbol ${}^{247}_{96}Cm$. It has
   a. 96 protons and 247 neutrons.
   b. 96 neutrons and 247 protons.
   c. 96 neutrons and 151 protons.
   d. 96 protons and 151 neutrons.

*37. Radioactive carbon dating depends on the
   a. quantity of carbon-14 in a sample.
   b. ratio of carbon-12 to carbon-14 in a sample.
   c. quantity of carbon-12 in a sample.
   d. None of the above answers is correct.

9

RELATIONSHIPS BETWEEN CHANGES



Activity 9.1 RELATIONSHIPS: A Thought Activity

On a sheet, answer each of the following questions.

Q. 1 You put a pot of cold water on the stove and turn on the heat until the water is just about to boil. Before the water starts to boil,

- a. what happens to its temperature as more and more heat is added to the water?
- b. are the quantity of heat added to water and the water's temperature related to each other, that is, is there a connection between them?

Q. 2 Your car is at the top of a long hill. You have the brake in the "off" position. The car slowly starts to roll down the hill.

- a. As the car moves down the hill, what happens to its speed?
- b. What is the connection between how far down the hill the car has moved and its speed?
- c. Is there a relationship (connection) between the speed of the car and its distance from the top of the hill?

Q. 3 It is raining steadily outside your house. There is a bucket standing in the rain. Is the height of the water in the bucket related to how long it rains?

Q. 4 It is late autumn. The leaves are beginning to come down from the trees. A strong wind starts blowing leaves down. Are the number of leaves left on the trees connected to how long the wind blows that day?

Q. 5 You press down on a thick square bar of iron. From what you can see, are the pressure that you exert and the height of the bar related?

Q. 6 Are the above relationships qualitative or quantitative?

Section 9.1 RELATIONSHIPS

You know what a relationship in a family is. It's when you are connected to someone by birth, marriage, or adoption. A scientific relationship is also a connection. It is a connection between things because they always change together (linked changes).

In this chapter, the discussion will be centered on variables which change together. (Variables were first discussed in Section 1.6 B.)

TWO VARIABLES ARE RELATED IF ONE OF THEM CHANGES WHENEVER THE OTHER ONE CHANGES.

If a change in one variable does not affect the other one, then the two are not related in this way. For example, the greater the volume of water in a beaker, the greater its mass. The two variables, volume and mass, are related because one of them always changes whenever the other one does.

Exercise 9.1

9-1 Which of the following show variables that are related to each other?

a. the number of large Chocaddict candy bars and their total weight
b. the speed of an object and the distance it covers in a given time
c. the quantity of air blown into a balloon and the size of the balloon, (until it breaks)
d. the quantity of air blown into a steel box and the volume of the box
e. the speed of a car and the time that it takes to go one mile

9-2 For each part of question 9-1, what happens to the second variable when the first one increases?

Section 9 . 2 TWO KINDS OF CHANGE

Relationships between variables that change together may be classified into two kinds: (1) direct and (2) inverse (or indirect).

9.2 A DIRECT RELATIONSHIP

TWO VARIABLES HAVE A DIRECT RELATIONSHIP
(that is, are directly related)
IF THEY ALWAYS BOTH CHANGE AT THE SAME TIME IN THE SAME DIRECTION

When two variables change in the same direction, they always either both get bigger or both get smaller. If one variable becomes bigger, so does the other. If one of them becomes smaller, the other becomes smaller.

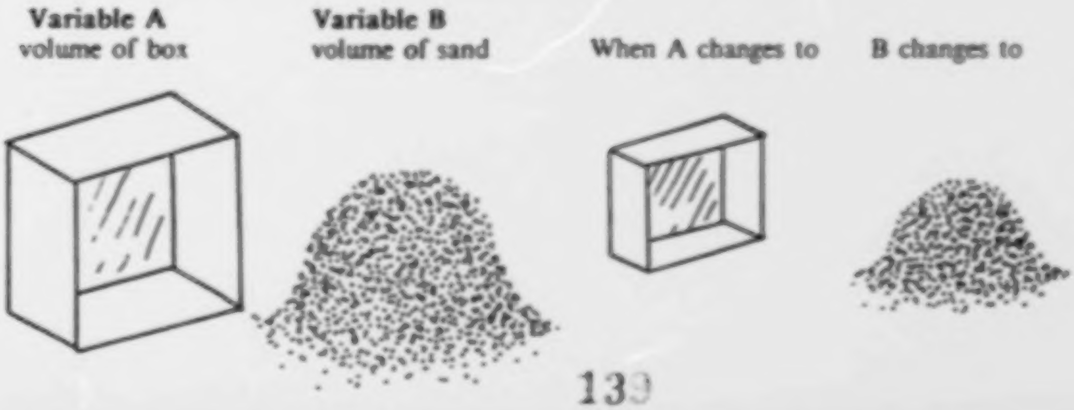
** Q. 1 Is the definition of a direct relationship, given above, qualitative or quantitative?

As an example of a direct relationship, consider the two variables, the DISTANCE that a car is driven at a steady speed, and the TIME that it is driven.

The longer a car is driven at the same speed, the greater the distance it goes. The shorter the time, the less distance it covers.

The time and the distance are directly related.

Below is an illustration of two variables which are directly related.



It doesn't matter which one changes first, Variable A or Variable B. The other one always changes in the same direction.

To describe the direct relationship with arrows:

A ↑, B ↑   A ↓, B ↓

Exercise 9.2 A

9-3 In Activity 9.1, which of questions 1 to 5 deal with a direct relationship?

9-4 Which of the following are direct relationships?

- a. the distance a car travels and the quantity of gasoline used up
- b. the number of baseballs and the weight of all the baseballs
- c. the number of slices of bread in a loaf and the volume that they take up
- d. the number of slices of bread in a loaf eaten and the number remaining
- e. the time a candle burns and the initial length of the candle
- f. the number of tables in this room and the color of your shoes

9-5 Each of the following choices shows the quantity of B for each quantity of A given. The units have been omitted. Which of these choices show direct relationships?

a.

A	B
1	3
2	4
3	5
4	6

b.

A	B
2	5
4	7
5	15
10	20

c.

A	B
5	1
3	3
2	8
1	15

d.

A	B
2	4
1	3
4	6
3	5

e.

A	B
6	7
7	6
8	12
12	8

f.

A	B
14	7
12	6
8	4
3	1

Answer to Q

Q. 1 The given definition of a direct relationship is qualitative. It tells what kind of a change occurs but not how much of a change takes place. It does not use quantities to describe the change.

9.2 B INVERSE (OR INDIRECT) RELATIONSHIP

The definition of an inverse (or indirect) relationship is as follows:

TWO VARIABLES HAVE AN INVERSE (OR INDIRECT) RELATIONSHIP
(that is, are inversely related)
IF THEY ALWAYS BOTH CHANGE AT THE SAME TIME IN OPPOSITE DIRECTIONS

When variables change in opposite directions,

one variable becomes SMALLER when the other gets BIGGER, or
becomes bigger when the other gets smaller.

As an example, consider the DISTANCE a car travels and the VOLUME OF GASOLINE LEFT in the tanks.

The farther the car travels, the less gas is left.
The less the distance traveled, the more gas is left.

The distance and the volume of gas left in the tank are inversely related.

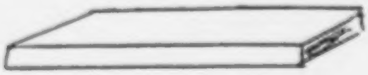
Exercise 9.2 B

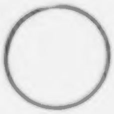
9-6 a. Fill in the blanks:
When two variables are inversely related to each other, one of them always gets ________________________ as the other becomes ________________________ .

b. The variables in an inverse relationship have been compared to the two ends of a seesaw. Explain.

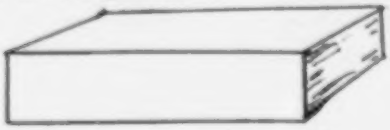
9-7 When there is an inverse relationship,

if C is **D is**





If C changes to **Draw below what happens to D.**



9-8 Fill in the arrows to complete the following.

To show an inverse relationship, when A ↑ , B _____.

when A ↓ , B _____.

9-9 In Question 9-4, which of the relationships is (are) inverse?

9-10 In Question 9-5, which of the choices shows an inverse relationship?

•Activity 9.2 THE BOUNCING BALL

Purpose: to observe relationships when a ball is bounced.

Materials: rubber ball, meter stick, graph paper

Hypothesis: When you drop a ball from a height to the ground, what is your hypothesis as to the relationship between the height of the drop and the height of the bounce?

Procedure: Obtain data to tell whether your hypothesis is correct. In your report sheet, describe how you obtained the data, and place the data into a table. Graph the data, placing the independent variable on the x-axis and the dependent variable on the y-axis and draw a line connecting the data points.

Question

Q 1 What are the causes of error in your measurements? That is, what caused them to vary when repeated due to conditions which you could not control?

Q 2 How does the overall shape of your graph line show the relationship between the two variables that you measured?

Q 3 How can you look at any line graph and tell whether or not the relationship is direct? For extra credit, answer Q 4.

Q 4 How could you look at any line graph and tell whether or not the relationship was inverse?

Conclusion: Write your conclusion and explain your reasoning.

Section 9.3 RULES FOR CALCULATIONS WITH MEASUREMENT LABELS

To arrive at many of their hypotheses, theories, and laws, scientists use quantitative knowledge of relationships. They must make measurements to do this. All measurements must be shown with measurement labels.

Measurement labels should ALWAYS be included in scientific calculations.

If 2 x 4 mm = 8 mm, what does 2 mm x 4 mm equal?

We shall look next at how to multiply and divide quantities. The rules for multiplication of quantities are shown first by examples and then by the rules themselves.

9.3 A UNIT - MULTIPLICATION

Examples of UNIT-MULTIPLICATION

(1) 2 mm x 4 mm = 8 mm x mm or
8 (mm)(mm) or
8 mm · mm or
8 mm^2

(2) 5 g x 3 cm = 15 g x cm or
15 (g)(cm) or
15 g · cm or
15 g-cm

(3) 3 m x 4 m x 100 m = 1200 m x m x m or
1200 m · m · m or
1200 (m)(m)(m) or
1200 m^3

RULES FOR UNIT-MULTIPLICATION

It can be seen that to multiply quantities,
(1) the numbers are multiplied together.
(2) the units are separately multiplied together.
(3) the numbers and units are joined together in the answer.

To show the product of two different units multiplied together, the units may be joined by a multiplication sign, brackets, a dash or a raised dot.

A unit multiplied by itself equals the unit squared, and multiplied by the unit again equals the unit cubed.

Exercise 9.3 A

Carry out the calculations indicated for the items below.

9-11 a. 2 km x 5 km
b. 5 x 16 g
c. 2 cm x cm x 18 cm
d. 0.5 s x 100.6 s

9-12 a. 10 g x 10 m
b. 0.3 cm x 9 mg
c. 8 x 2 g x 9

9-13 a. 4 g x 3 cm x 0.1 cm
b. 7 x 2 m x 6 kg x 0.1 m
c. 100 g ÷ 100 g

9.3 B UNIT- DIVISION

Examples of unit-division are given next, followed by the rules for unit-division.

Examples of UNIT-DIVISION

(1) $\dfrac{9\text{ kg}}{2\text{ m}} = \dfrac{4.5\text{ kg}}{\text{m}}$ or $4.5\ \dfrac{\text{kg}}{\text{m}}$

(2) $\dfrac{9\text{ kg}}{9\text{ kg}} = 1$

(3) $\dfrac{4\text{ kg}}{6\text{ kg}} = \dfrac{4}{6} = \dfrac{2}{3}$

(4) $\dfrac{8\text{ m}^2}{2\text{ m}} = \dfrac{8\text{ m} \times \cancel{\text{m}}}{2\,\cancel{\text{m}}} = 4\text{ m}$

RULES FOR UNIT-DIVISION

When dividing quantities, rules similar to those for multiplication apply.

(1) Numbers are divided.
(2) Units are divided.
(3) Units and numbers are joined together in the answer.
(4) When the denominator is one of some quantity, *i.e.*, 1 measurement unit, the "1" is omitted.

Note that a measurement label divided by itself equals one.

Carry out the calculations indicated below.

Exercise 9.3 B

9-14 a. $5\text{ g} \div 2\text{ cm}$
b. $2\text{ g} \div 5\text{ cm}$
c. $2\text{ g} \times 5\text{ cm}$

9-15 a. $10\text{ cm} \div 5\text{ cm}$
b. $5\text{ cm} \div 10\text{ cm}$
c. $5\text{ cm} \div 10\text{ cm}^2$

9-16 $(30\text{ g})\,(\text{g}) \div 15\text{ g}$

9-17 $30\text{ cm}^3 \div 10\text{ cm}^2$

9.3 C UNIT-MULTIPLICATION COMBINED WITH UNIT DIVISION

Multiplication and division of quantities can be combined as shown next. Again, the numbers are multiplied and divided and the labels are separately multiplied and divided. Numbers and labels are combined in the answer.

Often, the label part of the expression can be simplified immediately by cancelling.

UNIT-MULTIPLICATION AND UNIT-DIVISION TOGETHER

$$(1)\quad \frac{24\ \text{kg} \times 3\ \text{m}}{12\ \text{kg}} = \frac{24\ \cancel{\text{kg}} \times 3\ \text{m}}{12\ \cancel{\text{kg}}} = \frac{24 \times 3}{12}\ \text{m} = 6\ \text{m}$$

$$(2)\quad \frac{(9\ \text{kg}^2)(4\ \text{m}^3)}{3\ \text{kg}\cdot\text{m}} = \frac{(9\ \text{kg} \times \cancel{\text{kg}})(4\ \text{m} \times \text{m} \times \cancel{\text{m}})}{3\ \cancel{\text{kg}}\cdot\cancel{\text{m}}} = \frac{9 \times 4}{3}\ \text{kg}\cdot\text{m}^2 = 12\ \text{kg}\cdot\text{m}^2$$

Any fraction such as, for example, $\frac{5\ \text{g}}{3\ \text{cm}}$, may be written as 5 g/3 cm.

Unit-multiplication and unit-division can be carried out even when the units of the answer don't seem to have any meaning. For example, consider the calculation, 5 rooms x 1 house = 5 rooms-house. A unit such as rooms-house (or room-house or room-houses, which are all the same unit) may have no meaning at all to us. However, 5 rooms/house has a real meaning. It says that there are five rooms *per* house.

When scientists carry out operations which lead to answers with unusual units, they analyze the units for their meaning; this can lead to new understandings. (The process is called dimensional analysis.)

Exercise 9.3 C

Carry out the calculations for the items below.

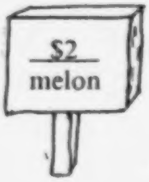
9-18 (70 g)(2 cm) ÷ 10 s

9-19 $\frac{40\ \text{kg}}{6\ \text{L}} \times 3\ \text{L}$

9-20 $\frac{\$40 \times 18\ \text{books}}{9\ \text{books} \times 2\ \text{students}}$

Section 9.4 THE PER FRACTION

You may have seen a sign like this in the supermarket:



(or $2/melon).

It means the same as $2 for a melon
or $2 per melon
or each melon costs $2.

***PER** means for each or for every.*
***A PER FRACTION** tells the quantity of one variable per quantity of another variable.*

Hence, 125 pages/book is a Per Fraction, as are

$\frac{1\ \text{min.}}{60\ \text{s}}$, $\frac{20\ \text{students}}{\text{classroom}}$, $\frac{100\ \text{cm}}{\text{m}}$, $\frac{0.001\ \text{kg}}{\text{g}}$, $\frac{36\frac{1}{2}\ \text{g HCl}}{40\ \text{g NaOH}}$, and $\frac{55\ \text{miles}}{\text{hour}}$.

** Q. 1 Are Per Fractions qualitative or quantitative?

A PER ONE fraction is a Per Fraction with a denominator of one measurement unit.

Per One fractions	Per Fractions but not Per Ones
100 cm/m	1000 cm/10 m (or 1 cm/0.01 m)
60 s/min.	1 min./60 s
10 females/male	1 male/10 females

Recall that the digit "one" is usually omitted when it is in the denominator of a Per One fraction. It is understood that an invisible "1" is there.

As with any fraction, the mathematical meaning of the **bar** in a Per Fraction is "divided by." Any Per Fraction can be reduced to its Per One. To convert a Per Fraction to a Per One fraction, divide the numerator (top) by the denominator (bottom).* For example, to convert $\frac{80\ \text{g}}{2\ \text{mL}}$ to a Per One fraction, divide 80 by 2 and g by mL:

$$\frac{80\ \text{g}}{2\ \text{mL}} = \frac{80}{2} \times \frac{\text{g}}{\text{mL}} = 40\ \frac{\text{g}}{\text{mL}}.$$

Similarly,

$$\frac{78.5\ \text{km}}{46\ \text{min.}} = \frac{78.5}{46} \times \frac{\text{km}}{\text{min.}} = 1.71\ \frac{\text{km}}{\text{min.}}$$

Exercise 9.4

9-21 Identify which of the following are Per Fractions.

- a. 7 days/week
- b. 8 grams
- c. $\frac{1\ \text{month}}{30\ \text{days}}$
- d. 12 eggs/dozen
- e. 1 piano/88 keys
- f. 88 keys/piano
- g. 15 days till Christmas
- h. 10/$2
- i. 6/5

9-22 Identify which of the choices in 9-21 are Per One fractions.

9-23 Convert the following Per Fractions to Per Ones. Use decimal numbers in the numerator instead of fractions.

- a. 80 hamburgers/40 boys
- b. 140 km/2 hrs.
- c. 4 NaOH/2 H_2SO_4
- d. 1 year per 365 days

Answer to Q

Q. 1 Per Fractions are quantitative. They have quantities in both the numerator and denominator.

---

*Dividing the numerator by the denominator to find the Per One is a short cut for carrying out this same operation by dividing the numerator and the denominator each by the same quantity. For example, to find the Per One for 75 g/3 cm, the long way is to divide 75 g and 3 cm each by 3 cm.

$$\frac{75\ \text{g}}{3\ \text{cm}} = \frac{75\ \text{g}/3\ \text{cm}}{3\ \text{cm}/3\ \text{cm}} = \frac{25\ \text{g}}{1\ \text{cm}} = 25\ \frac{\text{g}}{\text{cm}}$$

Section 9.5 THE PER ONE RULE

Science depends strongly upon mathematics; modern science could not exist without mathematics. No introductory course can properly teach science without including some mathematics.

Using mathematics in science can be made easy for you. The next chapter will teach you a simple method of scientific problem solving which is not only easy but can also be used in your outside-of-class activities. You have already learned most of what you will need to know in order to use this method.

This section will begin the process of learning how to easily solve science problems. You will be using Per Fractions. On a separate sheet of paper, solve the following problems. Be sure to include both the numbers and the measurement labels in your answer.

Problem (1) 2 feet at $\frac{12 \text{ inches}}{\text{foot}}$ = ______________________ inches

Note that feet and foot are really the same measurement label for length even though the English language uses a different form for the plural and the singular.

Problem (2) 10 m x $\frac{100 \text{ cm}}{\text{m}}$ = ______________________

Problem (3) 3.5 hrs. x $\frac{60 \text{ min.}}{\text{hr.}}$ = ______________________

Why do these arrangements work?

We suggest that the above arrangements work because they are each based on the Per One Rule.

> **THE PER ONE RULE**[*]
>
> If you know how much of one variable PER ONE of another, then if the one variable changes by any multiplier, so does the other.

For example, if there are 10 *pills* PER ONE *bottle*, then when the one bottle changes to five bottles (changes by a multiplier of 5), the pills also change to become five times as much as before (5 x 1 bottle = 5 bottles; 5 x 10 pills = 50 pills). If the variable, *bottles*, becomes ten times as big as before, the other variable, *pills*, also becomes ten times as big. If one variable changes by a multiplier of one-half, the other becomes half as big. **Both always change by the same multiplier.**

In Problem (1), if you know that there are 12 inches for 1 foot, it follows that for two feet there are 24 inches, twice as much.

$$\underset{\text{twice as much}}{\longrightarrow} 2 \text{ ft.} \times \frac{12 \text{ in.}}{\text{ft.}} = \overset{\swarrow \text{twice as much}}{24} \text{ in.}$$

When feet change by a multiplier of 2, so do inches.

For Problem (2), the Per One Rule says that if you know how many centimeters there are per 1 m, then for 10 m, there are ten times as many centimeters.

For Problem (3), if there are 60 minutes per one hour, for 3½ hours there are 3½ times as many minutes as in one hour.

---

[*] The formal statement of the Per One Rule is as follows. If you know how many units per one of a variable, then for x times that variable, it is x times as much (where x is any positive non-zero number).

Below is a problem and its solution.
Problem: Tishanta averaged 8 minutes per mile in the half-marathon. If she ran 12.2 mls, how long did it take?
Solution:

$$12.2 \text{ miles} \times \frac{8 \text{ minutes}}{\text{mile}} = 97.6 \text{ minutes}$$

**Q. 1 Explain the solution in terms of the Per One Rule.

Exercise 9.5

9-24 Fill in the blanks for b. to e. below, and explain each solution using the Per One Rule. For example, the solution to a. below is 134.4 days, and the explanation is, "In 5.6 days, there are 5.6 times as many hours as there are in one day."

a. $5.6 \text{ days} \times \frac{24 \text{ hours}}{\text{day}} = \underline{\hspace{6cm}} \text{ hours}$

b. $300 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = \underline{\hspace{6cm}} \text{ seconds}$

c. $40 \text{ g A} \times \frac{120 \text{ g B}}{\text{g A}} = \underline{\hspace{6cm}}$

d. $2.4 \text{ milliliters} \times \frac{0.001 \text{ liters}}{\text{milliliter}} = \underline{\hspace{6cm}}$

e. $0.6 \text{ gallons milk} \times \frac{4 \text{ quarts}}{\text{gallon}} = \underline{\hspace{6cm}}$

Answer to Q

Q. 1 For 12.2 miles it takes 12.2 times as many minutes as it takes for 1 mile.

Section 9.6 THE PER ONE RULE APPLIES TO ANY PER FRACTION

Suppose that a problem is given with a Per Fraction that is not a Per One fraction. You could first reduce the Per Fraction to its Per One. However, that isn't even necessary. Every Per Fraction equals its Per One. For example,

$$\underset{\text{Per Fraction}}{\frac{1000 \text{ cm}}{10 \text{ m}}} = \underset{\text{Per One Fraction}}{\frac{100 \text{ cm}}{\text{m}}} \qquad \text{and} \qquad \underset{\text{Per Fraction}}{\frac{120 \text{ miles}}{2 \text{ hours}}} = \underset{\text{Per One Fraction}}{\frac{60 \text{ miles}}{\text{hour}}}.$$

Since the Per Fraction equals its Per One, it doesn't matter whether the Per or the Per One Fraction is used. The Per One Rule applies either way.

For example, in the calculation below,

$$\frac{1 \text{ mL}}{2.6 \text{ g}} \times 50 \text{ g} = 19.2 \text{ mL}$$

the Per Fraction, 1 ml/2.6 g, equals its Per One fraction (which is 0.38 mL/g). The calculation shows that, in this case, there are 50 times as many milliliters for 50 g as there are for 1 g. The Per Fraction in this expression works just as well as the Per One fraction which it equals.

Exercise 9.6

9-25 Fill in the blanks below and explain using the Per One rule.

a. $14 \text{ gallons gasoline} \times \frac{\$5.40}{5 \text{ gallons gasoline}} = \$ \underline{\hspace{6cm}}$

b. $150 \text{ m} \times \frac{1 \text{ km}}{1000 \text{ m}} = \underline{\hspace{6cm}} \text{ km}$

Activity 9.3 HOW MANY ATOMS ARE THERE IN A TENPENNY NAIL?

Purpose: to use the Per One Rule in the laboratory to find out the number of atoms in a piece of matter.
Materials: one tenpenny iron nail
Your Guess: How many atoms of iron do you think are in a tenpenny nail? Recall that atoms are exceedingly small. Your teacher will show you a tenpnny nail. Write down your guess as to how many atoms are in it.
Procedure: At the front of the room is a sample of iron which is labeled with the following information describing it: name of element, atomic number, atomic mass, volume, mass, number of atoms in it.

Obtain a tenpenny nail. Find out how many atoms are in it. You may use any of the information about the iron sample at the front of the room, and any of the laboratory tools that are available in the classroom. You must use the Per One Rule to find your answer.

Write a laboratory report in which you record your observations. Show the arrangements that you use for your calculations. Answer the following questions.

Questions

Q. 1 How many atoms are present in your iron nail? Round off your answer to two numbers followed by "$x\ 10^y$" where y stands for the number of zeroes. For example, you might have a number such as 12×10^{24}.

Q. 2 Calculate how many atoms are present, according to your data, in 56 g of iron.

Section 9.7 TWO PER FRACTIONS FOR EACH RELATIONSHIP

If there are five boys per every six girls, is it also true that there are six girls per every five boys?

The answer is yes. For the relationship between boys and girls, both

$\frac{5\text{ boys}}{6\text{ girls}}$ and $\frac{6\text{ girls}}{5\text{ boys}}$ may be written.

Both ways of stating the relationship are correct (but the Per Fractions do not equal each other).

If there are 100 centimeters per meter, there is one meter per 100 centimeters.
If there are 2 eyes per nose, there is one nose per two eyes.
If there are 3 pens/$1, it is also true that there is $1/3 pens.
If there are 7 days/week, there is 1 week/7 days.

The inverse (upside-down) of a number or of a quantity or of any fraction is called its ***RECIPROCAL.***

(Any number or quantity or fraction equals one when multiplied by its reciprocal.)

EVERY PER FRACTION CAN BE EXPRESSED IN TWO WAYS, BOTH AS THE GIVEN FRACTION AND AS ITS RECIPROCAL.

Exercise 9.7

9-26 For each of the following, state the reciprocal:
  a. 6.8 g/cm
  b. 24 hours/day
  c. 30 g/min.
  d. 88 keys per piano

(Exercise 9.7 is continued on the next page)

9-27 Convert each of the reciprocals from 9-26 b, c, and d to its Per One. For example, the reciprocal for 9-26 a, is 1 cm/6.8 g. The Per One for 1 cm/6.8 g is 0.147 cm/g.

For 9-28 and 9-29 following, express the number part of your answers in decimals, not fractions. Give answers to 3 decimal places.

9-28 Give two Per Fractions for each of the following.
  a. 9 players to a team
  b. 1000 m in each km
  c. 55 miles an hour
  d. 1 boy to a girl
  e. 1 g equals 1000 mg

9-29 Give two Per One fractions for each of the following.
  a. There are 7 days to a week
  b. 1000 g = 1 kg.

* * *

Chapter 9 Review

Vocabulary

Indirect
Direct
Per One Fraction
Bigger
Related

Connection
Inverse
Reciprocal
Smaller
Per Fraction

In each blank in items 1 to 9, fill in one of the vocabulary words from the above. Each of the vocabulary words may be used only once.

1. Two properties are ______________________ if one changes whenever the other changes.

2. Another term for *indirect relationship* is ______________________ relationship.

3. The relationship between two variables is ______________________ if they both change in the same direction at the same time.

4. The relationship between two variables is ______________________ if they change in opposite directions at the same time.

5. When variables change in opposite directions, one variable becomes smaller when the other gets ______________________ , and becomes bigger when the other becomes ______________________.

6. Another word for relationship is ______________________.

7. The ______________________ of a fraction is what it becomes when its numerator and denominator exchange places.

8. The quantity of one variable per one measurement unit of a different variable is called a(n) ______________________ .

9. Quantity of numerator variable per quantity of denominator variable:

______ __________ ________ .

Applications

1. Reduce each of the following to simplest form.
   a. 164 g ÷ 16.4 cm

   b. 24 g ÷ 12 g

   c. 42 noses x 84 eyes ÷ 42 faces

   d. $\frac{18\ \text{cm}^2 \times 1\ \text{m} \times 1\ \text{m}}{1\ \text{cm} \times 1\ \text{cm}}$

   e. 60 kg x 3.3 m^2 ÷ (3 m x 6 L)

2. Which of the following show(s) a direct relationship between the two paired variables?

a.

A	B
3	6
4	18
5	20
6	21

b.

C	D
18	7
6	2
24	17
3	1

c.

E	F
3	21
4	18
5	15
6	12

d.

G	H
100	10
80	7
40	3
20	1

3. Which of the choices in Item 2 above show(s) an inverse relationship?

4. Identify each of the following as describing
   a. a direct relationship.
   b. an inverse relationship.
   c. variables with no relationship.

   (1) The bigger the pill, the less the number of pills which can be placed into the bottle.

   (2) The greater the pressure on the gas, the less volume it occupies.

   (3) The greater the mass of the salt, the more grains of salt there are.

   (4) The intensity of the light is increased but there is no change in the size of the object.

   (5) The faster the car goes, the more distance it can cover.

   (6) The faster the car goes, the less time it takes to get there.

5. Identify each of the following as describing
   a. a Per One
   b. a Per Fraction but not a Per One
   c. not a per relationship

   (1) 1000 m/km;

   (2) 1 hour/60 minutes;

   (3) $1/dozen;

   (4) 1 century/100 years;

   (5) 5 grains per 0.625 grams

6. Write the Per One for each of the following.
a. number of centimeters per meter ____________________
b. number of players on a football team ____________________
c. number of meters per centimeter ____________________

7. When two variables are related, (select the best choice)
a. they are developed out of the same idea.
b. they are controlled.
c. they always change.
d. they change at the same time.
e. they always change in the same direction.

8. Which of the following show(s) a direct relationship?
a. 2.7 g of aluminum occupies 1 cm^3; 5.4 g aluminum occupies 2 cm^3.
b. The more slices of bread are eaten, the less are left.
c. Two kilograms cost $46; twenty kilograms cost $300.
d. In one second, the object fell 4.9 m. In two seconds, the object fell 19.6 m.

9. Which of the choices in item 8 above show(s) an inverse relationship?

10. Write the reciprocal for each Per One in Question 5. Express the numbers in decimals, not fractions.

11. Explain the solution to each of the following in terms of the Per One Rule.

a. $8 \text{ cm}^3 \times \frac{2.7 \text{ g aluminum}}{\text{cm}^3} = 21.6 \text{ g aluminum}$

b. $5 \text{ kg} \times \frac{\$23}{\text{kg}} = \$115$

c. $5 \text{ kg} \times \frac{\$46}{2 \text{ kg}} = \$115$

•12. In the graphs below, draw a different line on each which shows two variables connected by a direct relationship. You do not need to number or title the graphs.

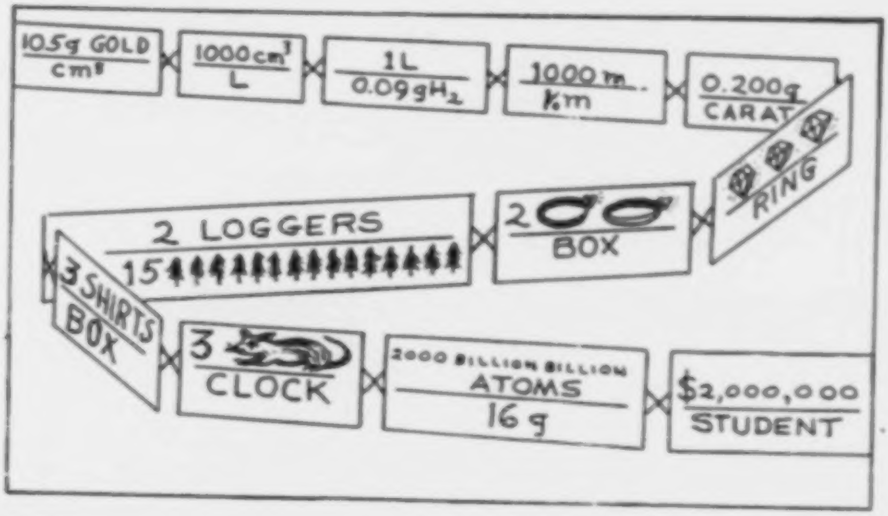
a.

b.

c.

10

PER PROBLEM SOLVING MADE EASY


10.5g GOLD / cm³
1000cm³ / L
1L / 0.09gH₂
1000m / km
0.200g / CARAT
RING
2 / BOX
2 LOGGERS / 15
3 SHIRTS / BOX
3 / CLOCK
2000 BILLION BILLION ATOMS / 16g
$2,000,000 / STUDENT

Introductory Activity 10.1 HOW DO YOU SOLVE THESE PROBLEMS?

Solve the following problems. Keep a record of how you do it. Time the start and finish for each problem, even if you finish by giving up. Your purpose in doing these problems is to compare the way you do them now with the way you do them after completing this chapter.

Problem 1: What is the volume occupied by 4.8 g of silver at room temperature? The density of silver is 10.5 g/cm³.

Problem 2: The fastest pitch officially clocked in a baseball game was thrown by Bob Feller (Indiana, 1946) and was recorded at 107.9 miles per hour (mph). How many seconds did Feller's ball take to get from him to home plate. The distance from the pitcher's mound to home plate is 60.5 feet.

We will return to these problems later. Hold on to the records.

This chapter will introduce you to an easy problem-solving technique which will help you to become good at solving problems, both in science and in your everyday activities. It is the kind of technique that becomes easier the more you do it and that requires no special knowledge of mathematics. We'll show you.

Section 10.1 UNITS WITHIN EQUATIONS

Science needs mathematics. Mathematics is needed to determine such things as speed, gasoline ratings, electric power, force, quantities of chemicals needed to react with each other, formulas of chemicals such as proteins, the structure of DNA, the distance to the sun, and so on and so on.

Because they work with quantities rather than numbers, scientists have a very powerful, simple problem-solving strategy which is not available for problems that use only numbers, not quantities. The strategy is called by several names among which is units analysis, the term we will use here.* You can use units analysis for your everyday consumer problems as well as for science ones and it is an easy method to use.

Units analysis is based on the Per One Rule. However, instead of arranging the quantities, only the units are arranged at first. This allows the problem solver to focus on the arrangement needed to solve the problem without distraction from the numbers, and it has other advantages as well, as you shall see.

The exercise given next will help lead you to the problem-solving techniques used in units analysis.

Exercise 10.1

The following exercise requires unit-multiplication and/or unit-division to fill in the blank(s) so that the units on both sides of the equation are equal. In this exercise, units are used without numbers. Just as with numbers on both sides of an equation, measurement labels must also be equal on both sides of an equation.

10-1 a. $\text{meters x } \frac{\text{grams}}{\text{meter}} = \boxed{\qquad}$

b. $\text{hours x } \frac{\text{minutes}}{\text{hour}} = \boxed{\qquad}$

c. $\text{cm}^3 \text{ x } \frac{\text{g}}{\text{cm}^3} = \boxed{\qquad}$

d. $\frac{\text{footballs}}{\text{player}} \text{ x player} = \boxed{\qquad}$

10-2 $\text{kilograms x } \frac{\text{meters}}{\boxed{\qquad}} = \text{meters}$

10-3 a. $\text{seconds x } \frac{\text{minutes}}{\boxed{\qquad}} = \text{minutes}$

b. $\text{liters x } \frac{\boxed{\qquad}}{\text{liters}} = \text{milliliters}$

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*Other names for units analysis (also called unit analysis) are: the factor-label method, dimensional analysis, quantity calculus, and unit factor method. Other names for Per Fraction are: conversion factor, rate.

10-4 $\text{g NaOH} \times \frac{\text{g HCl}}{\text{g NaOH}} = \boxed{}$

10-5 $\text{mL acid} \times \frac{\text{mL base}}{\boxed{}} = \text{mL base}$

10-6 a. $\text{kilograms} \times \frac{\boxed{}}{\text{kilograms}} = \text{centimeters}$

b. $\text{km} \times \frac{\boxed{}}{\text{km}} = \text{millimeters}$

10-7

$\text{kilometers} \times \frac{\boxed{}}{\boxed{}} = \text{kilograms}$

10-8 a.

$\frac{\boxed{}}{\boxed{}} \times \text{cubic centimeters} = \text{grams}$

b.

$\frac{\boxed{}}{\boxed{}} \times \text{shirts} = \text{dollars}$

10-9 a. $\text{square centimeters} \times \boxed{} = \text{acres}$

b. $\frac{\boxed{}}{\boxed{}} \times \text{days} = \text{hours}$

10-10 $\frac{\text{kg m}^2}{\text{s}^2} \times \boxed{} = \text{m}$

Section 10.2 UNITS ANALYSIS

10.2 A WHAT IS UNITS ANALYSIS?

Mr. Yanisaga needs to buy 25 liters of a chemical for his physical science class at $1.84 per liter. How much money will he need for the purchase? He calculates the answer as follows:

$\text{25 liters} \times \frac{\$1.84}{\text{liter}} = \$46$

The above can be explained by the Per One Rule. If it costs \$1.84 for one liter, then it costs 25 times as much for 25 liters.

** Q. 1 Why can't the cost in dollars/kilogram be used in the above expression instead of dollars/liter?

In any equation using quantities, the units must be *consistent, that is, the units on the left side of the equation must equal those on the right.*

To introduce the special problem-solving technique called units analysis, let's solve the same problem starting with the measurement units only. From the above, it can be seen that the problem starts with liters and ends with dollars.

$$\text{liters} \times \frac{\boxed{}}{\boxed{}} = \$$$

As in the exercise in the previous section, it can be seen that the blanks can be filled in with

$$\text{liters} \times \frac{\$}{\text{liters}} = \$$$

Now that the units are arranged, all that is needed is to fill in the numbers that go with the units. The arrangement needed for the solution is already set up.

$$25 \text{ liters} \times \frac{\$1.84}{\text{liter}} = \$46$$

The problem has been solved by letting the units guide you to the answer!

This is units analysis (also called the factor-label method). In this method, the units are arranged first and the numbers are inserted later. Any problem involving a Per Fraction may be solved by units analysis. Units analysis works because of the Per One Rule as can be seen from the arrangement that was set up. The measurement labels identify the variables for you and help you set up the solution.

Following is another example of a units analysis problem. With units analysis, there are four steps that are useful to get to the answer. They are shown in the solution to this problem which follows.

Example No. 10.1

Problem: A diamond has a density of 3.3 grams for every cubic centimeter of diamond. What is the volume in cubic centimeters of a diamond with a mass of 5.0 g?

Solution

Step 1: We start by finding out what unit is needed in the answer. In this example, we are looking for the number of cubic centimeters, so the unit of the answer must be cubic centimeters. The arrangement of units starts out as

$$= \_\_\_\_\_\_ \text{ cm}^3$$

Step 2: Next, list what is given. We were given a diamond of mass 5.0 g and density of 3.3 g/cm^3.

Step 3: Let's set up the needed arrangement, knowing that we are starting with grams and ending up with cubic centimeters.

$$\text{g} \times \_\_\_\_\_\_ = \_\_\_\_\_\_ \text{ cm}^3$$

The "grams" need to be canceled out while the "cubic centimeters" need to be multiplied in, so place g into the denominator (bottom) and cm^3 into the numerator (top) of the fraction.

$$\text{g} \times \frac{\text{cm}^3}{\text{g}} = \text{cm}^3$$

Before continuing, let's check the expression.

$$\cancel{g} \times \frac{cm^3}{\cancel{g}} = cm^3$$

This gives us the arrangement needed to solve the problem.

Step 4: Now, the expression can be completed by putting in the numbers to match the units.

$$5.0\ g \times \frac{cm^3}{3.3\ g} = \underline{\qquad}\ cm^3$$

Next, the answer is calculated. It is 1.5 cm^3. Once again, the answer has been easily found!

Exercise 10.2A

10-11 What is the special technique used in units analysis?

10-12 In Example No. 10.1, the type of information given in Step One is the unit of the answer. What type of information was written down

- a. in Step 2?
- b. in Step 3?
- c. What happened in Step 4?

10-13 Any problem involving _________________________ (complete the blank) can be solved by units analysis.

Answer to Q.

Q. 1 The cost of the chemical in dollars per kilogram can't be used because the given quantity is in units of liters, not kilograms. ***The units on the left side of the equation must equal those on the right.*** *When dollars/kilogram are used, the units on the left side come out to* $\frac{\text{liters x dollars}}{\text{kilogram}}$ *while the right side is in liters; the two sides aren't equal.*

10.2 B FOUR STEPS TO PROBLEM SOLVING

When solving any problem, the first thing to do is to read the entire problem. To solve a Per problem, there are four steps after reading the problem (you need to learn these steps by heart).

Step 1 (find): Put down the unit of the answer.

Step 2 (given): Put down what is given-- the quantities, Per Fractions, and any other information.

Step 3 (arrange and check): Arrange the units to lead to the desired unit in the answer. Check that the arrangement of units does give the wanted unit.

Step 4 (calculate): Insert the numbers next to their units in the expression. Carry out the calculations.

Some more sample problems follow.

Example 10.2

Problem: A train travels 360 kilometers in 2 hours. If the train continues at the same speed, how far will it travel in 13 hours?

Solution:

Step 1 (find): We want to know "how far." This is a distance; in this problem, the speed is given in kilometers per hours so distance should be measured in kilometers. Write down

= ____________ km

Step 2 (given): 360 km/2 hrs., 13 hrs.

Step 3 (arrange and check): An arrangement of units is needed which ends with the wanted unit. Let us start with the given quantity. The given quantity is 13 hours, so start with hours. Leave space for the Per Fraction needed.

hrs. x ________________ = km

In the Per Fraction, divide by hours (put hours into the denominator) to cancel the starting quantity. Multiply by kilometers to end up with kilometers in the answer.

$$\text{hrs.} \times \frac{\text{km}}{\text{hrs.}} = \text{km}$$

Check: the units are consistent.

Step 4 (calculate): Set the numbers that go with each measurement label into the equation and calculate the answer.

$$13\text{ hrs.} \times \frac{360\text{ km}}{2\text{ hrs.}} = \underline{\qquad\qquad}\text{ km}$$

= 2340 km. The train will travel a distance of 2340 km.

Wait a minute! In Example 10.2, 360 km/2 hrs. is not a Per One fraction. Shouldn't it first be reduced to a Per One fraction?

You could reduce it, but it isn't necessary. As was discussed in Chapter 9, the Per Fraction equals its Per One fraction;

$$\frac{360\text{ km}}{2\text{ hrs.}} = \frac{180\text{ km}}{1\text{ hr.}}$$

Any fraction that is equal to the Per One fraction may be substituted for it. This is a general rule for any units analysis problem.

The answers to the Q's in the following sample problems will be found immediately after the problem. The Q's are inserted to help walk you through the problem; work it through on a separate sheet of paper.

Example 10.3

Problem: Suppose Example 10.2 is reversed by asking how long it will take for a train to travel 2340 kilometers if it covers 360 km in 2 hrs.

Solution

Step 1 (find): We are looking for time. Since the given speed uses hours, hours should be the units of time in the answer.

= hrs.

Step 2 (given): 2340 km, 360 km/2 hrs.

Step 3 (arrange and check):

This step arranges the units to lead to the correct units in the answer.

****Q. 1 Is the desired answer a quantity or a Per Fraction?**
****Q. 2 Write the preliminary arrangement of units needed for the solution, to include the given and what is wanted but leaving a space for the Per Fraction.**
**Q. 3 A Per Fraction is needed. What unit should be in the denominator of the Per Fraction? Put it into your arrangement.
**Q. 4 What unit should be in the numerator of the Per Fraction? Put it into your arrangement.
**Q. 5 Check that the arrangement does lead to the units wanted in the answer.

Step 4 (calculate):
**Q. 6 In the arrangement of units that you have set up, insert the numbers which belong next to each unit. This is the final arrangement needed to find the answer.
**Q. 7 What is the answer?
**Q. 8 Which Per Fraction was used in the arrangement, the given one or its reciprocal?

Answers to Q's
Q. 1 quantity

Q. 2 $\text{km} \times \underline{\qquad\qquad\qquad} = \text{hrs.}$

Q. 3 $\text{km} \times \frac{\qquad\qquad}{\text{km}} = \text{hrs.}$

Q. 4 $\text{km} \times \frac{\text{hr.}}{\text{km}} = \text{hrs.}$

Q. 5 $\cancel{\text{km}} \times \frac{\text{hr.}}{\cancel{\text{km}}} = \text{hrs.}$ *The units check.*

Q. 6 $2340 \text{ km} \times \frac{2 \text{ hrs.}}{360 \text{ km}} = \underline{\qquad\qquad} \text{ hrs.}$

Q. 7 $2340 \text{ km} \times \frac{2 \text{ hrs.}}{360 \text{ km}} = 13 \text{ hrs.}$

Q. 8 the reciprocal

Example 10.4

Problem: Given 4.5 meters. Convert to kilometers.

IN THE FOLLOWING, COMPLETE THE BLANK WHEREVER THERE IS A Q.

Solution

Step 1 (find): = Q. 1 ________

Step 2 (given): Q. 2 ________________

Step 3 (arrange and check):

Q. 3 ________ x --------?--------- = Q. 1 ____________

Q. 3 ________ x $\frac{\text{Q. 5}}{\text{Q. 4}}$

Q. 6 Do the units check?

Step 4 (calculate):
You weren't given the kilometers per meter but YOU KNOW this. There are 1000 meters per kilometer. For Q, 7, be careful to place the correct number to go with its unit.
Q. 7 Insert the numbers next to the units to obtain the final arrangement.
Q. 8 What is the final answer?

Answers to Q.'s
Q. 1 *km*
Q. 2 *4.5 m*
Q. 3 *m; m x ----?---- = km*
Q. 4 $m; \quad m \times \frac{\_\_\_\_\_\_\_\_}{m} = km$
Q. 5 $km; \quad m \times \frac{km}{m} = km$
Q. 6 $\cancel{m} \times \frac{km}{\cancel{m}} = km$ *The units check.*
Q. 7 $4.5\ m \times \frac{1\ km}{1000\ m} = \_\_\_\_\_\_\_\_\ km$
Q. 8 $= 0.0045\ km$

Exercise 10.2B
Use the method of units analysis for all of these problems. Show Steps 1 to 4 for each problem.
Set A

10-14 The Fast Foodery sells hamburgers at $1.15/hamburger. How much do six hamburgers cost?

10-15 There are 78 pages per book. How many pages are there in eight of the books?

10-16 "Don't harm a hair on my infant's head," she shouted. The infant has 15 hairs per square centimeter. Its entire scalp measures 36 cm^2. How many hairs are there on the infant's head?

10-17 How many liters are needed to drive 500 km with a car that gets 7 km per liter?

10-18 a. There are 4 atoms of oxygen per every 2 atoms of hydrogen in sulfuric acid. How many atoms of oxygen are there for one million atoms of hydrogen?

b. There are 23 g sodium per 40 g lye. How many grams of sodium are there in 169 g lye?

10-19 The density of copper is 8.92 g/cm^3 at room temperature.
a. How many grams are there in 125 cm^3?
b. What is the volume of 10.0 g copper?

10-20 There are 0.911 grams of butterfat per milliliter of butterfat.
a. What is the mass of 75 mL of butterfat?
b. How many milliliters are occupied by 100 g butterfat?

10-21 What is the volume occupied by 4.8 g of silver at room temperature? The density of silver is 10.5 grams/cubic centimeter. Compare your solution with the way you did it in Activity 10.1.

10-22 One kilometer equals 0.6214 miles.
a. A ten-kilometer run is how many miles?
b. A ten-mile run is how many kilometers?
c. Joseph drove down Florida's Turnpike at 75 km/hr. The speed limit is 65 miles per hour. Was Joseph exceeding the speed limit? Show your calculations.

(Set A is continued on the next page.)

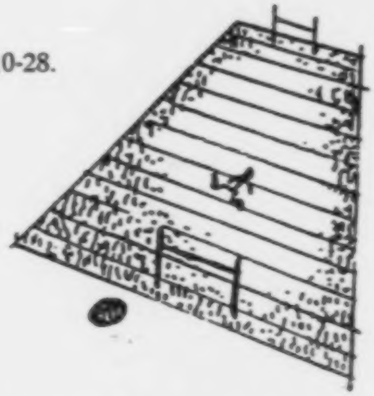
10-23 If a bird in the bush can eat 60 berries in 5 minutes, how long will it take the bird to eat 350 berries?

10-24 Oliver has 72 smurfs. There are 16 umps to every 47 smurfs. How many umps does Oliver have?

Set B

10-25 Given a distance of 2.5 km, how many meters is this?

10-26 Given a distance of 0.45 m, how many kilometers is this?



The following equalities may be needed for Problems 10-27 and 10-28.

1 centimeter = 10 millimeter
1 inch = 2.54 centimeters

10-27 A garden slug crawled 150 mm.
- (a) How many centimeters did it crawl?
- (b) How many meters did it crawl?

10-28 A basketball player is 190 centimeters tall.
- (a) How tall is the player in meters?
- (b) How tall is the player in inches?
- (c) How tall is the player in feet?

10-29 A running back averaged 7.1 yards/carry in a recent game; he carried the ball eighteen times. What was his total yardage?

10-30 There are 12 atoms of carbon per molecule of table sugar. How many atoms are there in 18 million billion molecules of table sugar (less than 1/4 teaspoon)?

10-31 There are 35½ g chlorine per 36½ g hydrochloric acid. How many grams of chlorine are there in 50 g hydrochloric acid?

10-32 A sugar solution holds 20 g/100 mL. How much solution is needed to hold 450 g sugar?

10-33 How many cubic centimeters are there in a cubic meter?

Activity 10.2 CAN YOU LIFT A POLYSTYRENE CUBE TWICE AS TALL AS YOU?

Purpose: to determine whether an ordinary person can lift a block made out of expanded polystyrene which is 2 m long on each side.
Materials: small block of polystyrene, centimeter ruler, laboratory balance
Procedure: Find the mass of a cube of polystyrene which is 2 m long, 2 m wide, and 2 m deep using the allowed materials. Be sure to use the four problem-solving steps. No report sheet has been prepared for you, so you should be sure to write down everything you will need to write your own report. In answering the following questions, show the arrangements needed for calculations; do not show the actual divisions and multiplications.
Hint: It will make the calculations easier if you convert the volume of the large block to cubic centimeters.

Questions:

Q. 1 What is your answer to the problem; that is, what is the mass of the large polystyrene cube? Show the four steps needed to obtain the answer.

Q. 2 List the causes of error. The "causes of error" are the conditions built into an experiment which cause unavoidable variations in data which could make your answer differ from someone else's. As an example, your block may have a dent in it that affects the calculations of volume.

Q. 3 Would you be able to lift a cube of polystyrene 2 m on each side? Explain. For your information, there are 2.2 lbs./kg.

Optional: Section 10.3 MULTI-STEP PROBLEMS

Units analysis is especially powerful when applied to problems which require more than one Per Fraction to solve the problem. The same rules of unit-multiplication and unit-division that you have already learned can be applied to a series of units operations.

Consider the following problem. If you spend a dollar a second for one year, how many dollars will you spend?

One way to solve this problem is to start with one year, convert it to days, then to hours, then to minutes, then to seconds, and then to dollars:

(1) $1\text{ year} \times \frac{365\frac{1}{4}\text{ days}}{\text{year}} = 365\frac{1}{4}\text{ days}$

(2) $365\frac{1}{4}\text{ days} \times \frac{24\text{ hrs.}}{\text{day}} = 8766\text{ hrs.}$

(3) $8766\text{ hrs.} \times \frac{60\text{ min.}}{\text{hr.}} = 525{,}960\text{ min.}$

(4) $525{,}960\text{ min.} \times \frac{60\text{ s}}{\text{min.}} = 31{,}557\ 600\text{ s}$

(5) $31{,}557{,}600\text{ s} \times \frac{\$1}{\text{s}} = \$31{,}557{,}600$

so you can spend about $30,000,000 in one year if you spend it at the rate of a dollar a second.

There is no need, however, to do each of the above steps separately. Instead of calculating the answer each time, just combine the steps into one grand expression as follows.

$$1\text{ yr.} \times \frac{365\frac{1}{4}\text{ days}}{\text{yr.}} \times \frac{24\text{ hrs.}}{\text{day}} \times \frac{60\text{ min.}}{\text{hr.}} \times \frac{60\text{ s}}{\text{min.}} \times \frac{\$1}{\text{s}} = ?$$

Simplify the expression and calculate the answer.

$$1\,\cancel{\text{yr.}} \times \frac{365\frac{1}{4}\,\cancel{\text{days}}}{\cancel{\text{yr.}}} \times \frac{24\,\cancel{\text{hrs.}}}{\cancel{\text{day}}} \times \frac{60\,\cancel{\text{min.}}}{\cancel{\text{hr.}}} \times \frac{60\,\cancel{\text{s}}}{\cancel{\text{min.}}} \times \frac{\$1}{\cancel{\text{s}}} = ?$$

$$\$\,365\tfrac{1}{4} \times 24 \times 60 \times 60 = \$31{,}557{,}600$$

The answer is the same as before!!!

Units analysis can be used to quickly set up complicated expressions. One after the other, Per Fractions can be set up that move the solution along to the final unit by "cancelling out" one unit and multiplying in a connected (related) unit. When the numbers are inserted into the expression, the solution can be calculated.

The following exercise will give you some practice in arranging the units.

Exercise 10.3

10-34 Simplify the following expressions (multiply and divide units).

a. $\text{m} \times \frac{\text{kg}}{\text{m}} \times \frac{\text{g}}{\text{kg}}$

b. $\frac{\text{dollars}}{\text{year}} \times \frac{\text{years}}{\text{week}} \times \frac{\text{weeks}}{\text{day}} \times \frac{\text{days}}{\text{hour}} \times \frac{\text{hours}}{\text{minute}}$

c. $\text{grams A} \times \frac{\text{moles A}}{\text{gram A}} \times \frac{\text{moles B}}{\text{mole A}} \times \frac{\text{grams B}}{\text{mole B}}$

d. $\text{volts} \times \frac{\text{amperes}}{\text{ohm}} \times \frac{\text{ohms}}{\text{ampere}}$

e. $\frac{\text{gallons}}{\text{quart}} \times \frac{\text{quarts}}{\text{pint}} \times \frac{\text{pints}}{\text{cup}}$

f. $\frac{\text{g}}{\text{cm}} \times \frac{\text{cm}^2}{\text{s}} \times \frac{\text{m}}{\text{cm}} \times \frac{\text{kg}}{\text{g}}$

10-35 In the following problems, use units analysis to get from the start to the finish. First, the units of a desired answer are shown. Then, the starting unit or Per Fraction is given. Some Per Fractions that will help you to get to the answer are shown next. You may have to use the reciprocals of some of the given Per Factions.

This a sample problem

Find: meters

Given: inches

Useful Per Fractions: $\frac{\text{m}}{\text{cm}}$; $\frac{\text{in.}}{\text{cm}}$

Solution: $\text{in.} \times \frac{\text{cm}}{\text{in.}} \times \frac{\text{m}}{\text{cm}} = \text{m}$

Solve a through d following.

a. *Find:* liters

Given: gallons

Useful Per Fractions: $\frac{\text{quarts}}{\text{gallon}}$; $\frac{\text{liters}}{\text{quart}}$

b. *Find:* carats

Given: rings

Useful Per Fractions: $\frac{\text{diamonds}}{\text{ring}}$; $\frac{\text{diamonds}}{\text{gram}}$; $\frac{\text{grams}}{\text{carat}}$

c. *Find:* miles per hour

Given: feet per second

Useful Per Fractions: $\frac{\text{hours}}{\text{minute}}$; $\frac{\text{miles}}{\text{foot}}$; $\frac{\text{seconds}}{\text{minute}}$

d. *Find:* kilograms

Given: m^3

Useful Per Fractions: $\frac{\text{g}}{\text{cm}^3}$, $\frac{\text{cm}^3}{\text{m}^3}$, $\frac{\text{kg}}{\text{g}}$

Optional: Section 10.4 SOLVING MULTISTEP PROBLEMS

The same four problem-solving steps and the same techniques as before can be used to solve multi-step Per problems. The ability to identify what is wanted, what is given, and where to start is a fundamental problem-solving technique which gives you a handle into any problem, whether a Per problem or some other kind. The more you practice this, the easier it gets.

Example 10.5

Problem: Given five grains of aspirin, how many ounces is that? There are 0.065 grams to a grain, and 28.3 grams/oz. Every tablet of regular aspirin has five grains of aspirin in it.

Solution

Step 1 (wanted): = oz.

Step 2 (given): 5 grains aspirin, 0.065 grams/grain, 28.3 grams/ounce

Step 3 (arrange): Start with the quantity. Leave a space for the Per Fractions that need to be filled in to get to the answer. Put down the unit of the starting quantity.

$$\text{grains} \times \qquad = \text{oz.}$$

The next step is to put a Per Fraction into the expression that cancels out the grains. Look for a Per Fraction that was given that has grains in it. We were given grams/grain. Put it into place.

$$\text{grain} \times \frac{\text{grams}}{\text{grain}} = \text{oz.}$$

This cancels grains out, and puts grams into the expression. The next step has to cancel grams out. What Per Fraction was given that had grams in it? Back at the "Given", grams/oz. were given. Put it in.

$$\text{grain} \times \frac{\text{grams}}{\text{grain}} \times \frac{\text{grams}}{\text{oz.}} = \text{oz.}$$

Oops! The way the above is set up, grams aren't canceled out but are squared instead. Take out grams/oz. Use the reciprocal of grams/oz.

$$\text{grain} \times \frac{\text{grams}}{\text{grain}} \times \frac{\text{oz.}}{\text{gram}} = \text{oz.}$$

The needed arrangement has been set up. Checking to be sure it is correct, we see that grains cancel out and grams cancel out, leaving ounces on the left side. It is correct.

Step 4 (calculate): All that is left to do is to insert the numbers and calculate.

$$5\ \text{grains} \times \frac{.065\ \text{grams}}{\text{grain}} \times \frac{1\ \text{oz.}}{28.3\ \text{grams}} = \underline{\qquad\qquad}\ \text{oz.}$$

$$= 0.011\ \text{oz.}$$

In the next sample problem, you are expected to know some of the Per Fractions yourself.

Example 10.6

Problem: Find the volume in liters of vinegar which contains 4.2 g acid. Acetic (pronounced uh-SEET-ik) acid is the only ingredient in vinegar besides water. Use the information that there are 5.1 g acid in 100 mL of a supermarket bottle of vinegar.

Solution

Fill in each blank where a Q appears.

Step 1: = Q. 1 ________

Step 2: Q. 2 ________________

Step 3:

$$\underline{\text{Q. 3}\qquad\qquad} \times \text{--------?--------} = \underline{\text{Q. 1}\qquad\qquad}$$

$$\underline{\text{Q. 3}\qquad\qquad} \times \frac{\text{Q. 5}}{\text{Q. 4}} = \underline{\text{Q. 1}\qquad\qquad}$$

The next Per Fraction needed is one you should already know.

$$\underline{\text{Q. 3}\qquad\qquad} \times \frac{\text{Q. 5}}{\text{Q. 4}} \quad \frac{\text{Q. 6}}{\text{Q. 7}}$$

Q. 8 Do the units check?

Step 4:

Q. 9 Insert the numbers that go with each unit. What is the expression?

Q. 8 What is the final answer?

Answers to Q.'s

Q. 1 *L*

Q. 2 *4.2 g acid, 5.1 g acid/100 mL vinegar*

Q. 3 *g;* *Q. 4* *g;* *Q. 5* *mL;* *Q. 6* *L;* *Q. 7* *mL*

Q. 8 $\cancel{g} \times \frac{\cancel{mL}}{\cancel{g}} \times \frac{L}{\cancel{mL}} = L$ *The units check.*

Q. 9 $4.2\ g \times \frac{100\ mL}{5.1\ g} \times \frac{1\ L}{1000\ mL} = \underline{\qquad\qquad}\ L$

Q. 10 $= \frac{4.2 \times 100}{5.1 \times 1000} \times L = 0.082\ L$

Exercise 10.4

For each of the following problems, use multi-step units analysis and show the 4 steps. Calculate answers to no more than one decimal place.

Set A

10-36 Jack took a tablespoon of ice cream from the quart container. Then he took another one. Before he knew it, he ate the whole container of ice cream. How many tablespoons did he eat? There are two tablespoons to an ounce and 32 ounces to a quart.

10-37 There are 48 bottles of concentrated hydrochloric acid to a carton. Each bottle costs $8.60. What is the total cost of 8 cartons?

10-38 How many centimeters are there to 1.65 km?

10-39 How many kilograms are there in 15,000 milligrams?

10-40 Mr. Athlete ran 10 km in 2.5 hr. There are 0.614 miles/km. If he maintained the same pace, how long would it take Mr. Athlete to run 10 miles?

10-41 Lisa drove 450 kilometers in her new sports car while in Europe. She gets 7.95 km to a liter and pays $0.79 per liter. What is the total cost for that distance?

10-42 A solution has 3.26 moles of glycerol in a liter of solution. There are 92.10 g of glycerine to a mole. How many grams of glycerine are in 10 L of solution?

10-43 The density of gold is 19.3 g/cm^3. A leaf of gold foil measures 10 cm x 10 cm x 0.02 cm. How many ounces (avoirdupois) of gold are there in the leaf if there are 28.3 g to an ounce?

Set B

10-44 There are 35 g of salt per 100 mL of solution. How many kilograms of salt are in 2.5 L of solution?

(Set B is continued on the next page)

10-45 A college student is 1.6 meters tall. The coach of the basketball team does not take anyone under 5 feet 11 inches for the varsity. Will the coach accept him? There are 2.54 cm per inch.

10-46 If 65 kg of zinc are needed to react with 73 kg hydrochloric acid, how many grams of zinc are needed to react with 12 g of acid?

10-47 A biologist counts the blades of grass in a 2 cm by 2 cm patch in a field and finds 18 blades. If the field is 100 m^2, how many blades of grass are on it, assuming that it all has the same growth of grass?

10-48 How many kilometers equal 430 dm?

10-49 For the problems below, the following table may be of help to you. You should already know any Per Fractions not in the table.

1 inch= 2.54 cm
1 mile = 5280 ft.
There are 2.2 lb/kg

LARRUP
LARRUP
GLOP

a. Ocean Airlines allows each passenger to take no more than 40 lbs. of luggage. What does this come to in grams? Round your answer to the nearest integer.
b. Which is longer, 3500 decimeters or 280 000 millimeters?
c. What is the length in meters of a quarter mile run?
d. How many grams are there to an ounce?
e. A dime is about 1 mm thick. How many dimes could be stacked to reach one foot in height?
f. The astronauts drove the Lunar Rover on the moon at 10 km/hr. What is this speed in miles per hour?
g. The atmospheric pressure at sea level is 14.7 lbs/in^2. What is the weight of air over one square foot of the earth's surface?

10-50 There are 16 glops to a grunt, and five grunts to a smurf. Each smurf gives off one-half an ump and there are 40 umps per 3 bumps. If every bump requires 25 larrups, how many larrups are there for every 8 glops?

10-51 There are 6 flims for every flam, and 2.8 flams per bam. For each bam, 4 bims are needed. There are 4 clinks per bim and 10 hunks per clink. Given 2 flims, how many hunks are there?

10-52 In a 1946 baseball game, Bob Feller, the Cleveland pitcher, pitched a baseball that was clocked at 107.9 mph, the fastest pitch in a baseball game on official record. If it is 60.5 feet from the pitchers' mound to the back of home plate, how many seconds did the ball take to cover that distance?

10-53 The speed of light is 186 000 miles/second. How far does light travel in a year? Round your answer to three integers.

Activity 10.3 **HOW MUCH IS A MILLION? A BILLION?**

Purpose: To get a feel for large and very large quantities

Procedure

Step 1:

a. How many meters long is a line of one billion dollar bills butted together on the short sides? Find out. Show your procedure and calculations.

b. Would one billion dollar bills go around the world? What do you think? Assume that the world is 25 000 miles in circumference? Show your calculations and explain your answer.

c. If the circumference of the world were exactly 25 000 miles, how many dollar bills would be needed to go around it?

Step 2:

a. If you had a million pennies, could you carry them all at one time (assume the container has no weight)? Find out. Use the laboratory balance to help you find the answer. Show your procedure and calculations. If you need to think in terms of pounds, use the information that there are 2.2 lbs./kg.

b. How many pennies could you pick up all at one time? You will need to estimate what the maximum mass is that you are capable of lifting. Show calculations and answer.

Question

Scenario: You are standing in a long line in front of the bank teller. When you get to the head of the line, photographers take flashbulb pictures of you and the bank president comes over to tell you that you have won a cash prize for patience. The bank tellers will give you a dollar per second for as long as you stand by the window until you have collected a million dollars. However, there is one catch. You cannot leave the window, go to sleep, or sit down. How long do you have to stand by the window to become a millionaire?

Complete the following table.

Dollars expressed in words	Numbers of Dollars	Numbers of Dollars in powers of ten	Time Required	
			Show calculations	Time
One	1	10^0	–	1 second
Thousand				____ minutes
Hundred Thousand				____ hours
Million				____ days

Report Sheet: Your Report Sheet should state the purpose, observations, calculations and answers, and the answer to the above question, including the table.

Chapter 10 Review

1 Fill in the needed units.

$$\text{liters} \times \frac{\boxed{}}{\boxed{}} = \text{decimeters}$$

$$\text{chemical A} \times \frac{\boxed{}}{\boxed{}} = \text{chemical B}$$

2. Arrange the units so that unit-multiplication and unit-division lead to the desired answer.

Given	Find
a. hours, and minutes per hour	minutes
b. cubic centimeters and cubic centimeters per liter	liters
c. moles and moles per gram	grams
d. start with beakers	milliliters

3. Name and describe the four steps needed to solve a units analysis problem.

4. Find the answers to the following problems by the method of units analysis. Show all four steps.

a. What is the mass of 20 liters of a liquid if the liquid masses 900 g per liter?

b. A recipe uses 1/4 bar of margarine for every 1½ cups of flour. How much margarine is needed for 5½ cups flour? Calculate to two decimal places.

c. There are 13 squelches to 3 smirks. How many smirks are there for 40 squelches? Calculate to the nearest integer.

5. Explain your answer to 4. a in terms of the Per One Rule.

*6. Work out the final units in these problems.

a. $\text{mm} \times \frac{\text{g}}{\text{L}} \times \frac{\text{L}}{\text{mm}} =$

b. $\text{km} \times \frac{\text{cm}}{\text{mm}} \times \frac{\text{m}}{\text{km}} \times \frac{\text{m}}{\text{cm}} =$

c. $\frac{\text{km}}{\text{hr.}} \times \frac{\text{m}}{\text{km}} \times \frac{\text{hr.}}{\text{min.}} \times \frac{\text{min.}}{\text{s}} =$

*7. Set up and solve.

a. given: kilograms
find: liters
useful per fractions: $\frac{\text{kilograms}}{\text{gram}}$, $\frac{\text{milliliters}}{\text{liter}}$, $\frac{\text{grams}}{\text{milliliter}}$

b. given: amperes
find: ohms
useful per fractions: $\frac{\text{volt}}{\text{ohm}}$, $\frac{\text{ampere}}{\text{coulombs}}$, $\frac{\text{volt}}{\text{coulomb}}$

*8. If an ant walks 0.01 meters per second, how long should it take to walk down Joseph's finger? Joseph's finger is 8.1 cm long.

*9. Convert 6250 mg to kilograms.

*10. 55 g of A react with 40 g of B. 36 g of B produce 80 g of AB. 25 g of AB react with C to produce 35 g of BC. How much BC can be produced from 100 g of A? Calculate to the nearest integer.

11

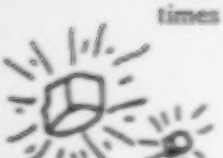
DENSITY, SPEED AND ACCELERATION

Section 11.1 WHAT IS DENSITY?

Suppose that you take a large crystal of rock candy and give it a sharp tap with a hammer. It splinters into many crystals of different masses, volumes, and shapes. Even though they are all so different, they all have the same density. So you see that density does not depend on the individual mass or volume of your sample. Density depends on mass AND volume. Each rock candy crystal has the same mass packed into every one cubic centimeter of volume. Density refers to the quantity of mass that can be packed into a given space.

There are 1.6 g of rock candy for every 1 cm³ of volume. All crystals of rock candy, no matter what the size, have the same quantity of mass packed into each one cubic centimeter. Densities differ depending upon the substance. Each cubic centimeter of salt has a mass of 2.2 g while a cubic centimeter of diamond has a mass of 3.51 g.

Density is the Per One fraction for mass/volume. For ten cubic centimeters, there is ten times as much mass as in one cubic centimeter.

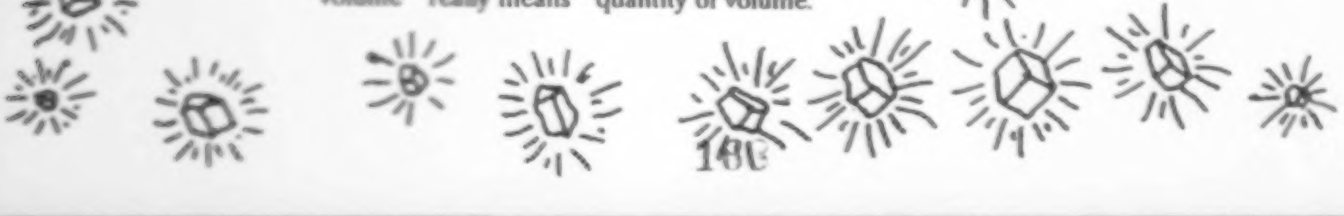


$$10\ \text{cm}^3 \times \frac{1.6\ \text{g}}{\text{cm}^3} = 16\ \text{g}$$

***DENSITY** is mass per volume.*

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Note that "mass" really means "quantity of mass" while "volume" really means "quantity of volume."



Also, density is a Per relationship, not a simple quantity.

**Q.1 Which is more dense, gold or wood? How do you know?

The more the mass of material that can be packed into the same space, the more dense is that material.

Densities are usually stated as Per One fractions. The measurement label for density may use any SI-metric units for mass divided by volume. In the laboratory where small quantities are handled, the unit for density is usually grams per cubic centimeter but it could be kilograms per liter or grams per cubic decimeter or any other appropriate unit.

Activity 11.1 WHICH IS MORE DENSE?

Purpose: to find out which is more dense, rubber or glass
Materials: laboratory balance, 100 mL graduated cylinder, rubber stoppers, glass marbles
Discussion Your task in this activity is to determine whether the rubber or the glass is more dense. You need to apply the definition of density, and to consider what you already know about ways to measure mass and volume. The rest is up to you.

Work with a partner or a team. Talk over what you will do and make a plan. Be sure that your teacher approves of your plan before you carry out this activity. Write a laboratory report of your activity.

Exercise 11.1

11-1 Which of the following show measurements of density? (Hint: density may be expressed as any Per Fraction whether or not it is equal to the Per One. Check the units for each choice.)

a. 6 g/cm^3
b. 4 cm^3 per g
c. 3 g/5 mL
d. 2 kg/m^3
e. 3 g^2/cm
f. 600 g/0.8 L
g. 6 g/cm^2
h. 18 m/kg^3

11-2 Calculate the densities of each of the following by reducing to the Per One fraction.
a. 15.5 grams marble filling 5 cubic centimeters
b. 100 cubic centimeters of cork with a mass of 22 g
c. 100 L of air massing 130 g

11-3 Which is more dense?
a. 1 pencil or 10 pencils
b. 5 kg lead or 5 g lead
c. 100 gallons water or 1 gallon water
d. 100 gallons water or 1 cm^3 marble

11-4 Which one in each of the following pairs is more dense?
a. 2.4 g/cm^3 or 1.8 g/cm^3
b. 2.4 g/cm^3 or 2.4 g/2 cm^3
c. 0.8 g/cm^3 or 0.7 g/cm^3
d. 0.8 g/2 cm^3 or 0.8 g/0.2 cm^3

11-5 Density comparisons always require equal ____________________.

11-6 Why is it wrong to say that steel is heavier than water, or that cork is lighter than water?

11-7 Is the relationship between mass and volume for a substance direct or indirect?

Answers to Q's

Q. 1 Did you answer that gold is more dense because it has more mass? But a ton of wood has much more mass than a golden apple. You can't find out which is more dense until the masses of equal volumes of gold and of wood are compared. If you have a shoe box filled with gold and an identical shoe box filled with wood, you can answer the question because you can compare the masses of these equal volumes. The mass of the gold packed into the box is greater than the mass of the wood that fits the same box, so the gold is more dense.

Section 11.2 DENSITIES OF SOLIDS, LIQUIDS, AND GASES

The densities of some substances at room temperature are shown in Table 11.1. On our Earth, matter ordinarily exists in three states, solid, liquid, and gas. As you can see from the table, there is a big difference between the densities of liquids and gases. Liquids are much denser than gases. A jar of air masses much less than the same jar filled with olive oil. The line between the densities of solids and liquids is not sharp although solids are usually denser than liquids. A cubic centimeter of water has a mass of 1 g; the same volume of salt has a mass of 2.2 g.

Table 11.1 Densities of Some Substances in g/cm^3*

	Density	Physical State		Density	Physical State
Ammonia	0.00077	gas	Water	1.0	liquid
Neon gas	0.00090	gas	Table salt	2.2	solid
Air	0.0013	gas	Aluminum	2.7	solid
Oxygen gas	0.0014	gas	Zinc	7.1	solid
Sulfur dioxide	0.0029	gas	Iron	7.9	solid
Cork	0.22	solid	Copper	8.96	solid
Maple wood	0.7	solid	Silver	10.5	solid
Rubbing alcohol	0.79	liquid	Uranium	19.1	solid
Olive oil	0.92	liquid	Gold	19.3	solid

The density of water, 1.0 g/cm^3, is worth memorizing.

Gases have densities much much smaller than that of water.

Most liquids have densities near to that of water.

Solids, with some exceptions, have densities at least twice that of water although their densities may be much greater.

Exercise 11.2

11-8 Arrange in the most likely order from least to most dense: liquid, solid, gas.

11-9 Given the following densities, state whether the substance is most likely to be a gas, a liquid, or a solid.

a. 0.002 g/cm^3; b. 14 g/cm^3; c. 0.86 g/mL;
d. 1.20 g/cm^3; e. 8.6 g/mL

11-10 Use units analysis to find your answers. Ether has a density of 0.71 g/cm^3.

a. Given 5.5 mL of ether, what is its mass?

b. Given 10 kg of ether, what is its volume in milliliters?

11-11 Given a metal with a density of 7.2 g/cm^3 that looks like aluminum but could be zinc or iron, use Table 11.1 to identify it.

---

*Since the volumes of substances can change with temperature and pressure, it is necessary to state the temperature and pressure at which density is given. If no temperature or pressure is shown, it means that the measurement was taken at 20°C (room temperature) and normal atmospheric pressure. Temperature and pressure have a big effect on gas volumes, a smaller one on liquids, and even less on solids.

Activity 11.2 IDENTIFICATION OF AN UNKNOWN SUBSTANCE

Purpose: to identify an unknown solid and/or liquid given a list of possible substances and their densities

Discussion: Each substance has a density which is characteristic of it. All samples of matter of the same identity should have the same density at the same temperature and pressure. Hence, density is one of the properties which can be used to identify a substance.

Materials: unknown material, beam balance, graduated cylinder, water

Procedure: Find the density of your unknown material. Use the density to identify the unknown material from a list of possible substances handed out by your teacher.

Conclusion: Identify the unknown substance (be sure to record its code mark.) Explain how you know this is the identity.

Section 11.3 DENSITY AND FLOATING

The tendency of a liquid or solid to float on top of a different liquid can be used to compare densities. Any material floating on top of a liquid is less dense than the liquid beneath it. If it sinks to the bottom, that material is more dense than the liquid.

**Q. 1 If a solid floats between top and bottom of a liquid, how does its density compare to that of the liquid?

When a solid floats on top of a liquid, the solid is said to be buoyant (BOY-uhnt) in the liquid.

Floating or sinking can provide a quick qualitative comparison of densities of solids and/or liquids. This test applies only to solids and liquids that do not dissolve in or react with the liquid in which they are placed.

Any solid whose density is greater than 1.0 g/cm^3 will sink in water. If the density of the solid is less than 1.0 g/cm^3, it will float on water.

Liquids that do not mix completely with water will collect above or below the water depending on density. Vegetable oil and water, for example, separate from each other after mixing; the oil floats on top because it is less dense. Mercury will settle below water.

Exercise 11.3

11-12 Samples of two liquids, A and B, are mixed together. Afterwards, they separate into two layers. A floats on B. Which is the denser liquid?

11-13 Ether has a density of 0.71 g/cm^3.

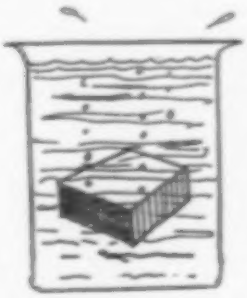
a. Will it float on water or sink?

b. Which of the following will float on ether? Refer to Table 11.1.

(1) cork; (2) olive oil; (3) salt

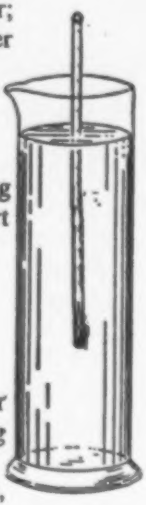
Answer to Q

Q. 1 If the solid floats within the liquid, it has the same density as the liquid.



Activity 11.3 A HYDROMETER (high-DROMM-uh-tuh)

Purpose: to construct and to use a hydrometer
Materials: wide straw 12-13 cm long, small piece oil-based clay, waterproof marking pen, ruler; three tall jars filled with water, saturated salt solution, and isopropanol respectively; paper towel, iron brads



Procedure:

Step 1: **MARKING THE HYDROMETER**

1. Obtain the materials.
2. Hold the ruler against the straw and place narrow lines along one side of the straw using the marking pens, with the lines one centimeter apart from each other, as on the ruler. Start at the top and do this for a total of ten centimeters.
3. Mark each of the half centimeters with a shorter line.
4. As best as you can, mark the quarter centimeters with a dot.

Step 2: **MAKING THE HYDROMETER**

1. Roll a small piece of clay into a wad wider than your straw and about 2 cm long.
2. Hold the clay wad vertically and slowly press one end of the straw into the clay as far as it can go. Your purpose is to plug the bottom of the straw so that it is leakproof. Plug it to a maximum of one centimeter of length.
3. Place the straw into the jar of water with the clay at the bottom. If it sinks to the bottom, you have used too much clay. Snip some clay off.
4. Holding the straw upright, drop in the metal brads until the straw floats with about half of its length upright in the water. The straw is now a hydrometer.

Step 3: **DATA COLLECTION**

1. Stir the hydrometer around in the water and against the sides to remove any air bubbles that are clinging to it.
2. Read the calibrated scale to obtain the length of the straw above the water. Enter in (1) on the Report Sheet.
3. Lightly dry the hydrometer with a paper towel and insert it into the jar of saturated salt solution. Stir to remove bubbles and take a reading. Enter in (2).
4. Similarly, take a reading in the isopropanol and enter in (3).

Step 4: **THE UNKNOWN**

1. Your teacher will give you a solution marked with a letter of the alphabet.
2. Be sure to record the letter on your Report Sheet under (4, a). This solution is your "unknown" solution.
3. Measure the length of float for the unknown and record in (4, b).

Step 5: **THE GRAPH**

1. Construct a graph with density on the Y-axis and straw length (above the liquid) on the X-axis. The density of your salt solution is 1.2 g/cm^3 ; the density of the isopropanol is 0.8 g/cm^3; plot these points. Plot the point for the water.
2. Draw a smooth line which fits the points as much as possible. Be sure that it is a smooth line, not bent at a sharp angle. The line may be curved.
3. Use the straw length for your unknown on the graph to find the density of the unknown solution.
4. Report the density of the unknown in (5) on the Report sheet.

Questions

Q. 1 Suppose you were given a solution of sodium bromide. It has a density of 1.4 g/cm^3. What should be its length of float on your hydrometer?

Q. 2 Clay and metal are both denser than water. Why does the hydrometer float if it has clay and metal in it?

Q. 3 How do air bubbles on its sides affect the hydrometer? Do they make it sink lower or float higher?

Section 11.4 THE USE OF SYMBOLS IN EQUATIONS

As shown in Section 11.1, the definition of density can be written as an equation. In its full form, it is written as

$$\text{density of a material} = \frac{\text{quantity of mass of the material}}{\text{quantity of volume of the same material}}.$$

A shorter way of writing this same equation is

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Always keep in mind that "mass" and "volume" in this equation stand for QUANTITIES.

Scientists shortcut such equations even further by using symbols. The symbols for the density equation are usually

d for density
m for mass
v for volume, so the equation becomes $\mathbf{d} = \frac{\mathbf{m}}{\mathbf{v}}$.

Usually, scientists select upper-case (capitals) or lower-case letters, but any symbols could be used such as the Greek letter ϕ (phi, pronounced feye) or even ♥ or ☺ .

Exercise 11.4

11-14 a. The volume of a box equals *length x width x height*. Select symbols for each of these variables, write down what they mean, and write the equation for the volume of a box using these symbols.

b. The volume of a sphere equals the product of $\frac{4}{3}$ multiplied by *pi* multiplied by the cube of the radius. Write an equation for this, defining the symbols you select.

Archimedes and the Crown

Archimedes was a famous Greek mathematician and inventor who lived from 287 to 212 B.C. His king gave him a difficult assignment. The king had given a goldsmith a quantity of gold to make into a crown. When the king received the crown, he began to wonder if it really had all the gold that he had given to the goldsmith. Perhaps the goldsmith had replaced some of the gold with some less valuable silver. The crown looked like gold and it weighed as much as the gold that the king had given to the goldsmith. Archimedes had to determine if the king had been cheated.

Archimedes puzzled over this. How could he find out? The answer came to him one day when he stepped into a tub full of water; water spilled over. "Eureka," shouted Archimedes, "I have found it." Archimedes took a chunk of gold equal to the original weight given to the goldsmith, put it into a vessel full of water and measured the overflow. He did the same thing for silver and for the crown.

Now, silver is half as dense as gold. Would there have been more water, less water, or the same overflow for the silver as for gold?

If silver had been used in the crown, even though the crown weighed the same as the original gold chunk, the crown would have occupied a larger volume than the gold chunk. Archimedes found that more water was displaced by the crown than by the gold. The goldsmith was a cheat!

Section 11.5 SPEED

An understanding of what speed is can be obtained by looking at its measurement label. For example, a sign on the highway reads, "MAXIMUM, 55 mph." What does *mph* stand for? It means miles per hour. The *per* immediately tells us that speed is a Per Fraction. Since *miles* is a measure of distance and *hour* is a measure of time, *SPEED* is the distance covered per time.

In 1984, Carl Lewis of the United States won a gold medal at the Olympics by completing 100 m in 9.99 s, so Lewis' speed was

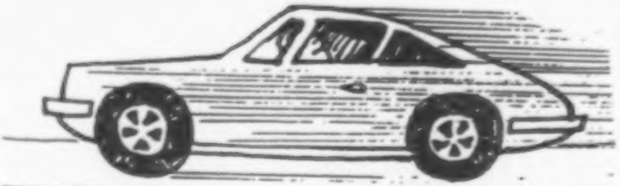
$$\frac{100\text{ m}}{9.99\text{ s}} = 10.01\ \frac{\text{m}}{\text{s}}$$

Speed is usually expressed as a Per One fraction. The equation for speed is

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}$$

In this equation,

speed means quantity of speed,
distance means quantity of distance,
time means quantity of time.



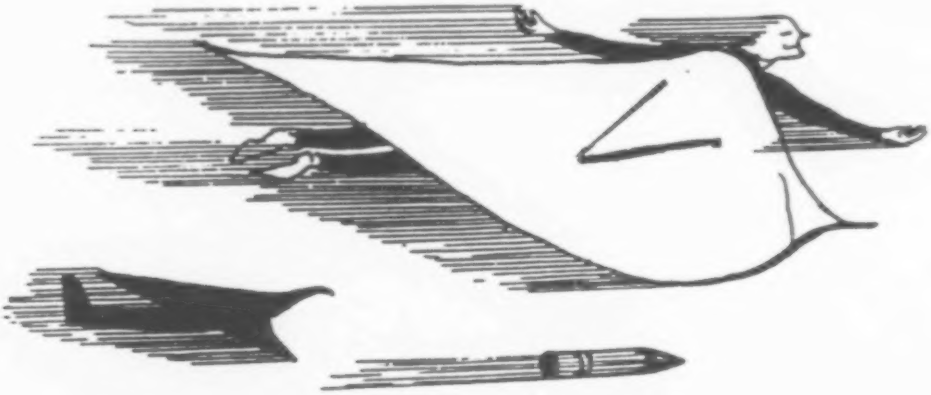
The equation using symbols, is

$$\boxed{v = \frac{d}{t}}$$

where

v = speed such as 10 m/s.
d = distance covered such as 100 m
t = time from start to finish, such as 9.99 s.

Calculations such as those involving speed or density can be carried out using units analysis. They may instead be carried out with the aid of the equation. A symbolic equation is a statement in mathematical shorthand. There are many different kinds of equations, but those like the one for speed ($v = d/t$) can serve as an algebraic shortcut for setting up a units analysis expression. As you will see in the sample problems, the equation has the needed arrangement built into it.



An equation may be used with any set of units, such as, in the case of the speed equation, km/s, miles per hour, or mm/day. On the other hand, units analysis applies only to the units in the given Per Fraction. Hence, an equation is a way of generalizing a relationship.

The units in an equation must be consistent; that is, the measurement labels on the left side of the equation must equal those on the right side. The same four problem solving steps are used as with units analysis except that in Steps 3 and 4, the arrangement involves an equation. The following problem on speed will provide practice in using an equation so as to become familiar with the method. This will be useful in working with equations in later chapters.

Example 11.1. What is the speed of an object that travels 35 km in 26 minutes? Solve using the equation for speed.

Solution

Step 1 (find): $v = \underline{\qquad\qquad} \frac{\text{km}}{\text{min.}}$

Step 2 (given): $d = 35$ km, $t = 26$ min.

Step 3 (arrange and check): Use the equation, $v = \frac{d}{t}$.

Substitute quantities. $v = \frac{35\text{ km}}{26\text{ min.}}$ (With equations, it is just as convenient to show the whole quantity rather than the units alone.)

Check: the units of the answer are km/min.; they check.

Step 4 (calculate): The answer needed is the Per One fraction.

Divide the numerator by the denominator,

$$v = \frac{35\text{ km}}{26\text{ min.}} = 1.3\text{ km/min.}$$

Activity 11.4 MEASUREMENT OF SPEED

Purpose: to calculate the speed of a stroll

Materials: classroom equipment as needed

Discussion: How fast does a person move who is just strolling along? A soldier with a full pack on forced march is expected to cover four miles in about fifty minutes.

Hypothesis: What is your best guess for the speed of strolling?

Procedure:

Step 1: Someone will be selected to walk at a steady (or uniform) pace from the front of the room directly to the back. Your task is to measure the speed. With your partner, develop a plan for carrying out the activity.

Step 2: Write up the plan and obtain your teacher's approval.

Step 3: When the class is ready, the walk or walks will take place. Carry out your measurements and obtain data.

Report: Write up a report in which you calculate the average speed of a stroll.

Exercise 11.5

11-15 What is the average speed of an automobile that travels 400 km in 6 hours? Use the 4 steps.

11-16 What is the average speed of an ice puck that travels 9 m in 5 s? Use the 4 steps.

11-17 What is the speed in kilometers/second of an object that travels 40 000 km in ½ hr.? Use the 4 steps. Calculate to one decimal place.

11-18 Which of the following choices has an error in it?
  a. s = 80 km/hr., t = 5 hr., d = 12 km
  b. s = 100 km/hr., t = 2 hr., d = 200 m
  c. s = 50 m/s, t = 10 min., d = 500 m

Optional: Section 11.6 UNIFORM SPEED VERSUS AVERAGE SPEED

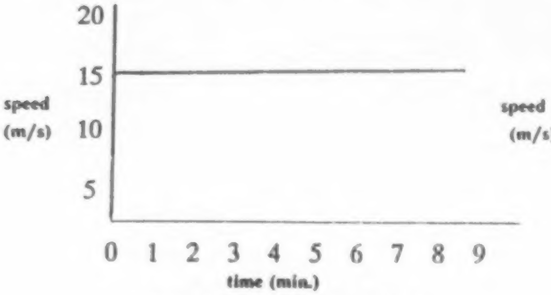
When motion takes place at the same speed throughout, the speed is said to be **UNIFORM**. Other words with the same meaning are **CONSTANT** speed, and **STEADY** speed.

Picture a truck which travels at a speed of thirty miles per hour except when it has stop for traffic lights and start up again. In one hour, it covers twenty miles.

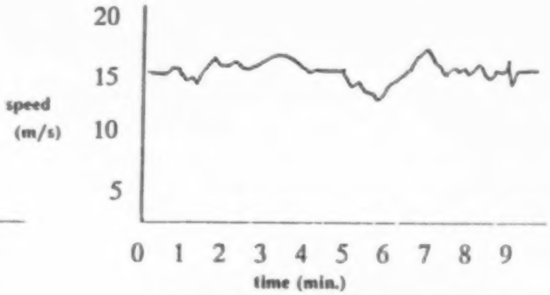
**Q. 1 What was the speed of the truck for the one hour?

**Q. 2 Did this truck move at a uniform speed during the hour?

The equation for speed, $v = d/t$, gives an average speed only. If an object moves at the same steady speed throughout the time that the speed is measured, then the average speed is also a constant or uniform speed. If the object's speed increases and/or decreases during this time, the speed for the total time is average but not uniform (not constant, not steady).



Graph of uniform speed
averaging 15 m/s



Graph of non-uniform speed
averaging 15 m/s

Exercise 11.6

11-19 A postal worker delivers the mail from house to house on a city street. Is the worker's average speed also a uniform speed?

11-20 Ordinarily, is the speed of a car on a highway constant?

11-21 A train travelled 80 miles in one hour. Can you be sure that this is
  a. an average speed?
  b. a constant speed?

Answers to Q's

Q. 1 20 miles/hour

Q. 2 No. Each time it speeded up or slowed down, its speed changed. Each time it stopped at a light, its speed changed.

Activity 11.5 WHICH CARS ARE EXCEEDING THE SPEED LIMIT?

Purpose: to identify the cars exceeding the speed limit
Materials: meter tape measure, stop watch
Procedure:

Step 1: **DISTANCE**

1. Each team will be assigned two reference points on the street to mark the beginning and end of the test distance.
2. Measure and record the distance between the two reference points. Enter on the Report Sheet in (1).

Step 2: **TIME**

Using a stopwatch, time as many cars as possible during the time of the experiment as they travel between the reference points. Assign a number to each car in the order of observing. Record the data in the table in (2) in the Report Sheet in the columns headed "Car Number" and "Time (seconds)".

Questions

Q. 1 What is the legal speed limit on the road that you used for the experiment?

Q. 2 Using units analysis, calculate the speed in meters per second for an object moving at the legal speed limit. To do this, you may wish to first convert the time in hours to the time in seconds. Then convert the distance in miles to the distance in meters. There are 0.62 miles to a kilometer. Show calculations.

Q. 3 Using the data collected, complete the following chart in (3) on the Report Sheet.

Car No.	Time (s)	m/s	Speeding Ticket (Y/N)

Q. 4 A car is exceeding the speed limit if it travels between reference points in less than ______________ seconds.

Q. 5 What percentage of the cars exceeded the speed limit during your period of observation? Show calculations.

Section 11.7 VELOCITY

In the equation for speed, the term velocity did not appear even though v is ordinarily used to represent speed. Scientifically, velocity (vuh-LAHS-it-ee) and speed have different meanings.

VELOCITY expresses both speed and direction.

For example, a car driving east at 40 miles per hour has a speed of 40 miles per hour and a velocity of forty miles per hour east. Its velocity is different from that of a car driving west at 40 miles per hour although they both have the same speed. The velocities differ because their directions differ.

A familiar example of the importance of velocity is rowing upstream. If the stream is moving east at one-half mile per hour while you are rowing west at two miles per hour, you will actually move with a velocity of only 1½ miles per hour west.

Velocities are very important at airports where controllers watch, track, and control the velocities of every airplane that approaches. They are also fundamental for such things as calculating long-range missile firings and rocket launchings. In baseball, the velocity of the ball at each instant (instantaneous velocity) is important.

Exercise 11.7

11-22 Suppose a person is walking forward through a long train moving at 50 miles per hour. The person is walking at 2 miles per hour in the same direction that the train is moving. What is the person's velocity with respect to the ground?

Section 11.8 FRAME OF REFERENCE

You are at the end car of a long train travelling at a fast speed. You are very hungry and remember that it is dinner time so you start to walk through the train to get to the dinner car which is about five cars in front of you. You move ahead at a reasonable speed, maybe one mile per hour. Beneath you, the train is moving at 60 miles per hour.

How fast are you moving?

If you said that you were moving at one mile per hour, then you were right because you were thinking of yourself with respect to the train floor beneath you. The train floor was your frame of reference. If you said 61 miles/hour, then you were also correct provided that your frame of reference was the ground beneath the train. It all depends on where you are locating the point or frame from which the change is taking place.

Did you ever sit in a car and suddenly think that it is moving only to find that it was not you but the car alongside that was moving? You had to switch from one frame of reference (the car alongside of you) to another frame of reference (the car in which you were sitting). It all depends on your frame of reference.

Let's go back to the train and consider that the earth below the train is also moving. It is revolving completely around the globe every 24 hours. From the point of view of someone off the earth, you are moving forward on the train while the train moves on the ground and the ground rotates around the earth's axis. Let's not forget that the entire earth also moves in orbit around the sun, that our solar system is moving around in the galaxy, and that the entire galaxy appears to be hurtling into the universe. Which frame (or point) of reference do you want to choose? Your speed will depend on that.

All perceptions of motion depend on the frame of reference. The formal way of stating this is to say that motion is relative to the chosen reference point.

In 1905, Albert Einstein published his famous theory of relativity. An important part of that theory stated that there is no way that you can tell whether something is moving or is at rest. If you think that you are not moving (which makes you the reference frame), then it may appear that another object is moving. However, if you decide that the other object is at rest (that it is the reference frame), you may have to decide that you are moving. You have no way of knowing which is which.

Exercise 11.8

•11-23 In the olden days, people believed that the sun moved around the earth. What was their reference point? What is the reference point today?

11-24 Suppose you go into a luxury elevator in a new building. Unfortunately, in the new elevator, the buttons over the door that should light up to tell you what floor you are reaching are not yet working. During the time between when you start and stop, how can you tell that you are moving?

11-25 You are in a boat on a stream. What is your speed with respect to the boat? Does it change if you select the water as the reference frame?

Section 11 . 9 ACCELERATION (ak-sell-uh-RAY-shun)

11.9 A ACCELERATION: QUALITATIVE

Acceleration is another Per Fraction but it is an unusual one in that it already has a Per Fraction in it. An object speeds up or slows down; while the speed is changing, the object is accelerated (ak-SELL-uh-rayt-ed).

ACCELERATION is the change in velocity per time.

To compare accelerations, it is necessary to compare both the change in speed and the time that it takes. That's because the less time it takes for the same change in speed, the greater is the acceleration. For example, imagine two cars next to each other waiting for the light to change. Both cars start to move at the same time and both cars speed up to fifty miles an hour. Car One does it in 12 seconds and Car Two does it in 20 seconds.

**Q. 1 Did both cars accelerate?
**Q. 2 Which car had the higher acceleration?

When the driver of a car jams down on the gas pedal to speed up a car, the acceleration is large because the time for the change in velocity is small. If the driver only gradually increases the velocity to the same final value as before, the acceleration is smaller because it took a longer time.

Since a change in velocity may be a change in direction without a change in speed, any change in direction is an acceleration.

Exercise 11.9 A

11-26 Which one has the higher acceleration, Michael who increases speed in 2 s or Jonathon who makes the same increase in speed in 4 s?

11-27 Which one has the higher acceleration, Rachel who sprints from 5 miles per hour to 10 miles per hour in 5 seconds or Anasha who sprints from 5 miles per hour to 11 miles per hour in 5 seconds?

11-28 A runner moving at a steady speed of five miles per hour turns a corner and keeps running at the same speed. Has the runner accelerated?

Answers to Q's

Q. 1 Both cars accelerated because both underwent a change in velocity.

Q. 2 Car One (which got to fifty miles an hour in 12 seconds) was the one which accelerated faster. It made the same change in speed but the change was made in a shorter time.

Optional: 11.9 B ACCELERATION: QUANTITATIVE

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$= \frac{\text{final velocity minus starting velocity}}{\text{time required for the change}}$$

We could call acceleration a Per Per Fraction. The measurement labels for acceleration must be in terms of $\frac{\text{velocity}}{\text{time}}$. Some samples of possible units for acceleration follow:

$\frac{\text{km/min.}}{\text{s}}$; $\frac{\text{mi./hr.}}{\text{min.}}$; $\frac{\text{m/s}}{\text{s}}$ which may also be written as $\frac{\text{m}}{\text{s}^2}$ or as m/s^2.

Exercise 11.9 B

11-29 An object has an acceleration of 10 m/s^2. How much does it speed up every second?

11-30 An object accelerates at $\frac{\text{8 miles/hour}}{\text{second}}$. How much does it speed up each second?

11-31 An object accelerates at $\frac{\text{-8 miles/hour}}{\text{second}}$. How does its speed change each second?

(Exercise 11.9 B is continued on the next page.)

11-32 Which of the following is the greater acceleration?

a. $\frac{10\text{ m/s}}{\text{s}}$ or 50 m/s^2

b. $\frac{20\text{ m/s}}{5\text{ s}}$ or $\frac{10\text{ m/s}}{2\text{ s}}$

c. $\frac{50\text{ cm/s}}{\text{min.}}$ or $\frac{50\text{ mm/s}}{\text{min.}}$

11-33 Which ones of the following could be acceptable units for acceleration?

a. m/s^2 d. m/s

b. km/hr.^2 e. $\frac{\text{yards/day}}{\text{min.}}$

c. $\frac{\text{s/m}}{\text{min.}}$ f. $\text{s}^2\text{/m}$

11-34 Use the four steps for each of the following.

a. What is the acceleration of a train which speeds up from 50 km/hr. to 120 km/hr. in 10 s?

b. What is the acceleration (negative) of a train which slows from 120 mph to 40 mph in 10 s?

◆ ◆ ◆

Review, Chapter 11

Vocabulary

Select the best choice for each of the following.

1. Density is ____________________ per unit of volume.
   a. distance; b. mass; c. heaviness; d. area
2. Any object undergoing an acceleration has a change in
   a. velocity; b. mass; c. time; d. volume.
3. ____________________ is the distance per unit of time.
   a. Speed; b. Mass; c. Volume; d. Uniform
4. *30 miles/hour going north* is best described as
   a. speed; b. velocity; c. distance; d. Per Fraction.
5. A solid which is buoyant in a liquid
   a. floats on top
   b. sinks to the bottom
   c. dissolves
6. A state of matter is: (select the best choice)
   a. a physical property.
   b. a chemical property.
   c. a liquid whenever the temperature is between 0°C and 100°C.
   d. not a property of matter.

In the following, match the units at the left to the best choice at the right.

7. miles/second	a. distance
8. kilograms/liter	b. speed
9. mm/s/min.	c. density
10. kilometers	d. acceleration

Which of the following are examples of acceleration? Write "yes" if it is and "no" if it isn't.

11. A train speeds up as it leaves the station.
12. A person walks at a steady pace.
13. A racing car maintains a steady speed around a wide turn.
14. An object falls off a table towards the ground.

Applications

The following questions are multiple choice. Select the best choice.

1. The state of matter characterized by both a definite shape and a definite volume is
   a. solid; b. liquid; c. gas; d. none of these.
2. Which is the most dense?
   a. 5 g air; b. 20 g air; c. both the same
3. Which is the most dense?
   a. 10 g/mL; b. 24 g/4 mL; c. 30 g/20 cm^3; d. 12 g/L
4. Which of the following is most likely to be the density of a liquid?
   a. 0.002 g/cm^3; b. 0.02 g/cm^3; c. 0.9 g/cm^3; d. 3.5 g/cm^3; e. 10.6g/cm^3
5. A density of 1.0 g/cm^3 is most likely to be the density of
   a. water; b. air; c. iron; d. cork.
6. Which of the following is a quantitative statement?
   a. Jennifer has grown much taller.
   b. John's speed is 5 miles per hour.
   c. Maria has the highest batting average.
   d. none of the above
7. Which of the following contain an error?
   a. v = 10 km/hr., t = 2 hr., d = 20 km
   b. v = 29 m/s, t = 10 s, d = 290 m
   c. v = 45 km/s, t = 50 s, d = 2150 km
   d. v = 72 mm/s, t = 2 hr., d = 144 mm
8. Which of the following is (are) units for speed?
   a. m/hr.; b. min./mile; c. hr./yard; d. cm/s^2; e. km/year
9. Which of the following is (are) units for density?
   a. g/cm^3 ; b. g/cm^2 ; c. kg/mL ; d. g/mm^3 ; e. cm^3/g
10. Which member of each the following pairs is denser?
    a. 2.6 g/5.2 cm^3 or 3.6 g/1.8 cm^3
    b. 0.8 g/cm^3 or 0.9 g/cm^3
    c. 10 g salt or 1 g salt
    d. 100 corks or 1 mL water

Find the answers to each of the following.

11. Given two slugs of metal. Each has a volume of 2 cm^3. Slug A has a mass of 15.7 g. Slug B has a mass of 14.2 g. Identify each from the following list of densities.

aluminum	2.70 g/cm^3	zinc	7.14 g/cm^3
iron	7.86 g/cm^3	nickel	8.90 g/cm^3

12. Given that the density of table salt (sodium chloride) is 2.2 g/cm^3, use the four steps to calculate the
    a. mass of 33 cm^3.
    b. volume of 33 kg.

13. Given two liquids, A with a density of 0.78 g/cm³ and B with a density of 0.92 g/cm³, which floats on top?

14. What is the speed of an object that travels 360 km in two hours? Use the speed equation and show the four steps.

15. Given that 126 g of a substance has a volume of 90 mL. Use the four steps and the density equation to calculate the density of the object.

16. You are driving a car along a straight road. If the car is chosen as the reference frame for motion, what is happening to all the objects you see as you turn your head to look out of the side window?

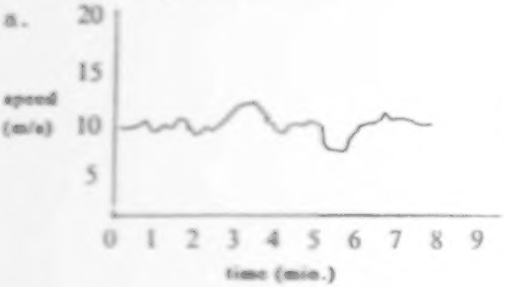
17. Your captors take you with them as they escape into the future. They put you by yourself into a car with no windows and seal the door. For a moment, you get a sensation that feels as if you being pressed backwards. Then, that sensation disappears. You strain your ears trying to hear, but there is no sound at all. Is the car moving? How can you tell?

*18. A car moved at an average speed of 55 miles/hour. Select the best choice.
  a. You can be sure that the car's speed never changed from 55 miles/hour the entire time.
  b. You can be sure that the car never went faster than 55 miles/hour.
  c. You cannot tell if this was a uniform speed.
  d. You can be sure that the car never went slower than 55 miles/hour.

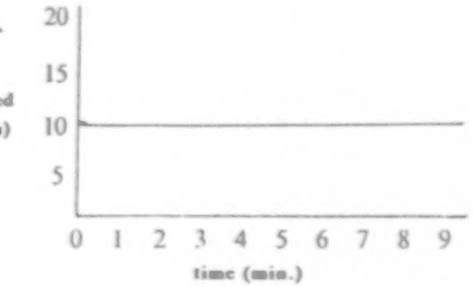
*19. A wheel turning at a steady 75 rotations per minute has a speed which is
  a. increasing; b. decreasing; c. changing; d. uniform.

*20. What is the average speed of the object shown in the graphs below? For each, state whether the speed is uniform.

a.



b.



*21. Which of the following accelerations is (are) bigger than 20 m/s²?
  a. $\frac{40\text{ m/s}}{5\text{ min.}}$; b. $\frac{80\text{ m/s}}{20\text{ s}}$; c. $\frac{60\text{ m/s}}{2\text{ s}}$; d. none of these choices

*22. An object was accelerated from 50 km/s to 90 km/s in 10 min. Its acceleration was
  a. $\frac{4\text{ km/s}}{\text{min.}}$; b. 4 km/s²; c. $-\frac{4\text{ km/s}}{\text{min.}}$; d. $\frac{40\text{ km/s}}{\text{min.}}$.

*23. An object is accelerated at 25 cm/s². The s² stands for
  a. square seconds.
  b. seconds per second.
  c. seconds squared.
  d. both b and c are correct.

*24. An stationary object is accelerated at 10 mi./hr./min. After two minutes, what is its speed?

12

THE PROPORTIONAL RELATIONSHIP

Activity 12.1 SPECIAL WORDS

The following paragraph in "A Tramp Abroad" by Mark Twain describes a special device used for horses. What is the name of the device?

The man stands up the horse on each side of the thing that projects from the front end of the wagon, throws the gear on top of the horses, and passes the thing that goes forward through a ring and hauls it aft, and passes the other thing through the other ring and hauls it aft on the other side of the other horse, opposite to the first one, after crossing them and bringing the loose end back and then buckles the other ring underneath the horse and takes another thing and wraps it around the other thing I spoke of before and puts another thing over each horse's head, and puts the iron thing in his mouth and brings the ends of these things after over his back, after buckling another one around under his neck, and hitching another thing on a thing that goes over his shoulder, and then takes the slack off the thing which I mentioned a while ago and fetches it aft and makes it fast to the thing that pulls and wagon, and hands the other thing up to the driver.

This text has introduced many special words used in science. Each word can save an entire paragraph of description when it is used. One of the most important words in science, proportional, will be introduced in this chapter.

Section 12.1 THE PROPORTIONAL RELATIONSHIP

The Per One Rule (Chapter 9) says that if you know how much for one thing, then for ten things, it is ten times as much. For example, given the Per Fraction, 60 miles/hour, if the one hour is changed to ten hours, then the distance also becomes ten times as much.

$$\frac{60 \text{ miles}}{\text{hour}} \times 10 \text{ hours} = 600 \text{ miles}$$

Similarly, if the time changes to ½ hr., then the distance covered become half as much, or 30 miles. When the distance become 320 times as big, the time required is 320 hours, and so on. The two variables in the Per Fraction always change by the same multiplier at the same time.

There is a special name for the relationship where two variables always change by the same multiplier. The name is ***DIRECTLY PROPORTIONAL.*** *Often, this name is simply shortened to* ***PROPORTIONAL.***

The Per Fraction, 60 miles/hour, shows two variables which are proportional to each other, distance and time. The two variables always change by the same multiplier. Proportional variables double at the same time, triple at the same time, change to become ten times as great at the same time, or become one-fifth as great at the same time. They always change together by the same multiplier. This is why all their Per Fractions always equal the Per One fraction.

$$\frac{60 \text{ miles}}{\text{hr.}} = \frac{2 \times 60 \text{ miles}}{2 \times 1 \text{ hr.}} = \frac{10 \times 60 \text{ miles}}{10 \times 1 \text{ hr.}} = \frac{1/5 \times 60 \text{ miles}}{1/5 \times 1 \text{ hr.}}$$

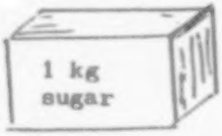
TWO VARIABLES ARE PROPORTIONAL TO EACH OTHER WHEN THEY ALWAYS CHANGE AT THE SAME TIME BY THE SAME MULTIPLIER.

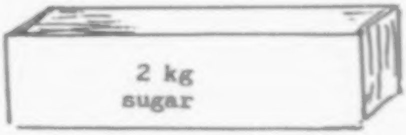
All of the Per Fractions shown so far had variables which were proportional to each other. That is because we restrict the term, Per Fraction, to labeled fractions where the two variables are proportional. The Per One Rule works only because the two variables are proportional to each other.

Per Fractions are Proportional Labeled Fractions.

In non-science usage, you may see labeled fractions which have variables that are not proportional to each other. For example, if paper is 40¢/pad and 75¢/2 pads, the number of pads has doubled but the new price is less than double the old one. The cost and the number of pads are not proportional to each other. They do not form Per Fractions.

The mass and volume of a sample of sugar are two variables which are proportional to each other. If the mass of the sugar doubles, the sugar will take up twice as much space. If the volume is five times as great as before, the mass must also be five times as great as before, and so on. As mass changes, the volume changes by the same multiplier. Hence, all the Per Fractions equal the Per One fraction.





WHENEVER TWO VARIABLES HAVE A PROPORTIONAL RELATIONSHIP, ALL THE PER FRACTIONS EQUAL THE PER ONE FRACTION.

Some examples of proportional relationships shown as Per Fractions are:

$$\frac{\text{wages}}{\text{week}}, \quad \frac{\text{blood corpuscles}}{\text{area on slide}}, \quad \frac{\text{cost}}{\text{hamburger}}, \quad \frac{\text{distance}}{\text{time}}, \quad \frac{\text{length in km}}{\text{length in m}}, \quad \frac{\text{mass A}}{\text{mass B}}$$

Exercise 12.1

12-1 Which of the following describe proportional relationships?

- a. \$20/shirt; \$40/2 shirts; \$60/3 shirts
- b. \$50 per dress, \$95 for two dresses
- c. 12 pencils per one pack, 36 pencils per three packs
- d. 100 cm/m
- e. 50 km/s, 75 km/2 s
- f. 30 grams per minute, 15 grams in 1/2 minute
- g. 3 tennis balls per can
- h. 12 mL/760 torr, 6 mL/1520 torr
- i. 12 slices eaten, 24 slices left; 24 slices eaten, 12 slices left

12-2 Which of the items in 12-1 describe direct relationships but not proportional relationships?

12-3 Examine the sample problem below and then apply it to fill in the blanks in the remainder of this item. For each, the two variables are proportional to each other.

Sample Problem 12.1 Fill in the blank.

$$\frac{\text{16 rotations}}{\text{second}} = \frac{\boxed{}}{\text{5 seconds}}$$

The seconds have changed from 1 to 5 so the common multiplier is 5. Both variables are proportional to each other. Therefore, the rotations must also change by being multiplied by 5.

16 rotations x 5 = 80 rotations

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a. $\frac{\text{30 g}}{\text{mL}} = \frac{\boxed{}}{\text{3 mL}}$

b. $\frac{\text{40 candies}}{\text{box}} = \frac{\boxed{}}{\text{20 boxes}}$

c. $\frac{\text{20 km}}{\text{4 hr.}} = \frac{\boxed{}}{\text{hr.}}$

d. $\frac{\text{6.6 bites}}{\text{cookie}} = \frac{\boxed{}}{\text{1/2 cookie}}$

12-4 For which of the relationships in 12-1, a. to i., can units analysis be used for calculations with them?

Activity 12.2 OVERHEAD PROJECTOR

Purpose: to find whether the length of a line drawn onto a transparency which appears on the screen is proportional to the distance of the projector from the screen

Hypothesis: State your hypothesis about length versus distance.

Materials: overhead projector, meter tape measure, overhead transparency

Procedure:

1. This is a class activity. First, a transparency is placed on the overhead projector. A horizontal line has been drawn on it.
2. You are going to obtain at least four sets of measurements. For Set 1,
   a. obtain the measurement for the distance from the projector to the screen. Call this D_1. Enter this on your Report Sheet.
   b. obtain the measurement of the length of the line projected onto the screen. Call this L_1. Enter this on your Report Sheet.
3. Obtain at least three more sets of data for length and distance, moving the projector each time, and record them, using D_2 and L_2 for Set 2 and so on.
4. Calculate the Per One fraction for each set of data.

Conclusion: What is your conclusion? Did your calculations agree with your hypothesis? Explain.

Section 12 . 2 FAMILIAR PROPORTIONALITIES

Two familiar Per Fractions have already been studied, density and speed. Both deal with variables which are proportional to each other.

Density equals mass per volume; the variables, mass and volume, can be written as the Per Fraction, mass/volume. The mass and volume of the same material both always change by the same multiplier. If the mass of a sample of the material triples, it is because three times as much volume of it is being used. If the mass becomes one-fifth of what it was, it will occupy only one-fifth as much space. The mass and volume of a given material are proportional to each other. Each Per Fraction, mass/volume, always equals the Per One fraction, speed.

Likewise, when the speed is uniform, distance and time are proportional to each other. Consider an inchworm crawling along the ground at a steady speed. If it crawls for less time than it did before, the distance it covers will become smaller by the same multiplier. If the distance covered increases, the time needed increases by the same multiplier. Speed is a Per Fraction. Each Per Fraction, distance/time, equals the Per One fraction, speed.

Exercise 12.2

12-5 a. When the mass of a substance changes by a multiplier of 0.5, what happens to its volume?
b. If the volume of a substance changes from 5 mL to 10 mL, what must happen to the mass which fills that space?
c. A train is travelling at 90 km/hr. How does the distance covered in 9 hours compare to the distance covered in 3 hours?

12-6 A student who is working part-time earns $150 per week.
a. If the student works for 16 weeks, will the student earn a total (before taxes) which is 16 times as much?
b. Which variables are proportional to each other?
c. What is the one word used to describe the above Per Fraction?

12-7 True or false: two variables which are directly proportional to each other are always directly related.

Activity 12.3 IS THIS A PROPORTIONAL RELATIONSHIP?

Purpose: to test whether two variables are proportional to each other

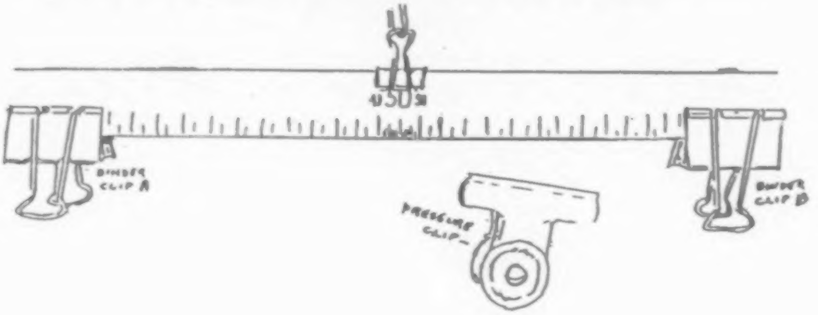
Hypothesis: The total mass set on one side of a lever is proportional to the distance from the pivot of a mass set on the other side.

Materials: meter stick, small binder clip (⅜" capacity), 3 large binder clips, (1½" capacity), #4 pressure clip, centimeter ruler, about 50 cm length of string, stand or tape to support the lever

Procedure:

Step 1: MAKING A LEVER

1. Install the small binder clip firmly onto the upper half of the horizontal meter stick so that it centers on the 50 cm mark.
2. Raise and close together the handles of the clip above the stick and slip one end of the string through them. Tie the string loosely so that the knot is about 10 cm above the handles.
3. Tie the other end of the string to a support so that it hangs less than 20 cm above the floor or base. You now have a lever. The clip assembly acts as the pivot.
4. Check that your stick is horizontal when allowed to swing freely. To do this, measure the distance from each end of the stick to the floor to see that they are the same.



Step 2: EXPERIMENTAL TESTING OF THE HYPOTHESIS

Set a large binder clip (Clip A) firmly on the lower half of the meter stick approximately 20 cm from the pivot. Balance it by setting another large binder clip (Clip B) on the other side, lower half, of the meter stick, nudging it into position as needed.

To test the hypothesis, double the mass on one side and then check whether the distance from the pivot to the mass on the other side also has to double to balance the lever. To double the mass on the side where clip B is, put the third large binder clip (Clip C) on the upper half of the meter stick precisely above Clip B.

You have now doubled the mass (Clips B and C together) on one side. Does Clip A on the other side have to be moved twice as far as before? Find out. Record your data neatly on the Report Sheet.

Step 3: A DIFFERENT STARTING MASS

So far, you have checked whether doubling the mass on one side of a lever requires that the distance of a balancing mass on the other side also has to be doubled. Suppose that the two starting masses (one on each side of the lever) are not identical (unlike Step 2). Do you think that the relationship will still be proportional? Keep in mind that the variables are the mass on one side and the distance on the other side.

To verify your hypothesis, first remove all the clips. Place the pressure clip about fifteen centimeters from the pivot. Balance it with one binder clip on the other side. After it is balanced, double the mass of the binder clip by placing a second binder clip above the first one. Does the pressure clip have to be moved to twice the distance it was before to balance the doubled mass? Carry out the test of the hypothesis, collecting and recording data.

Questions

Q. 1 Explain the difference between Step 2 and Step 3.

Q. 2 Has the hypothesis been proven? What is your conclusion. Discuss, including whether or not more tests need to be conducted.

Q. 3 List the causes of error, that is, the conditions that caused variations in your data that you could not control.

Section 12.3 THE PER EQUATION

Our knowledge of the proportional relationship and our knowledge of Per Fractions can be combined to create a general equation for any proportional relationship.

In Chapter 11, two equations were examined,

the density equation: $d = \frac{m}{v}$ and the speed equation: $v = \frac{d}{t}$.

Of course, either equation can be reversed: $\frac{m}{v} = d$, and $\frac{d}{t} = v$.

For each of these, the two proportional variables are shown on one side as a Per Fraction. The other side of the equality is a constant such as 50 miles per hour for v or 2 g/mL for d.

The constant that the Per Fraction equals in an equation is called the **constant of proportionality**. It is frequently given as the Per One fraction, as in speed or density.

There are many such equations for proportional variables. The Per Fractions in all of these can be represented by $\frac{y}{x} = k$ where **y** and **x** are two variables which are proportional to each other and **k** is the constant of proportionality.

$$k = \frac{y}{x}$$

SIMPLEST EQUATION FOR A PROPORTIONAL RELATIONSHIP

Keep in mind that **y** stands for the quantity of a variable and **x** stands for the quantity of another variable proportional to it.

**Q. 1 If y becomes five times as big, what must happen to x?

**Q. 2 If x is multiplied by 0.23, what must happen to y?

Exercise 12.3

12-8 Given the density equation for mercury, name the variables and the constant.

12-9 Given the equation, $y/x = a$ where a is constant.

a. When x is multiplied by 4, what happens to y?

b. When x changes by the multiplier, $\frac{1}{10}$, what happens to y?

c. When y changes from 4 to 40, what happens to x?

d. When y is multiplied by q, what happens to x?

e. What is the general rule when x changes in the equation, $\frac{y}{x} = a$ where a is constant?

12-10 Suppose two variables, A and B are proportional to each other. Write an equation which shows this relationship. (Hint: use A and B instead of x and y.)

12-11 Given that q and s are proportional to each other. Show this by an equation.

(Exercise 12.3 is continued on the next page.)

12-12 If y and x are directly proportional to each other, are y and x also directly related?
12-13 Two variables, a and b, are directly related to each other. Does this mean that they are also proportional to each other?

Answers to Q's
Q. 1 x becomes five times as big as before.
Q. 2 y changes by a factor of 0.23.

Section 12.4 TWO FORMS OF THE GENERAL EQUATION FOR PROPORTIONAL VARIABLES

Many relationships in the sciences are expressed by equations, each written with symbols standing for variables. Equations show relationships in a short, quantitative, exact way. Scientific equations differ from the ones taught in algebra in that each symbol has real meaning. Each symbol represents the quantity of a variable which exists in nature.

It is a big advantage in studying science to be able to recognize which variables in equations are directly proportional to each other.

The equation, $y/x = k$ can be rearranged to $y = kx$ (or $y = xk$).*

> Anytime that y and x are arranged as
> $y/x = k$ or
> $y = kx$,
> y and x are proportional to each other.

In the equation, $y/x = k$, k stands for a constant. Any other symbols can be substituted for k as long as they stand for a constant. Any other symbols can be used for y and x as long as they stand for proportional variables. The equation for a direct proportion cannot include variables which are either added or subtracted such as $y = kx + b$ or $y = kx - c$. Hence, it is possible to tell whether two variables in an equation, such as y and x, are proportional to each other. The test for proportionality is that

(1) y and x are arranged as a fraction (y/x or x/y)
OR (2) y and x are on opposite sides of the equation (both in the numerator or both in the denominator)
AND (3) nothing is added to x or y, or subtracted from x or y.

Two sample problems on recognizing whether two variables in an equation are directly proportional are shown next. In checking whether two variables are proportional to each other, it is always assumed that everything else in the equation is held constant.

Example 12.1 Are m and n proportional in the equation $m = an$?

Solution: Since m and n are on opposite sides of the equation (in the same arrangement in $m = an$ as are y and x in $y = kx$) and since a is a constant (because everything but m and n is held constant), m and n must be proportional to each other.

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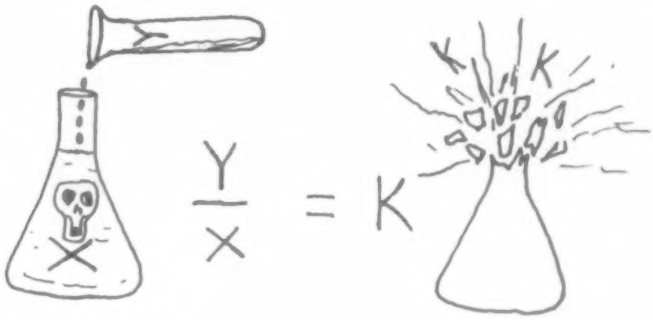
*The shortcut for rearranging an equation is to cross-multiply. The rules for this are as follows. (1) Start with an equation. (2) A symbol from the numerator on one side can be moved to the denominator on the other side. (3) A symbol from the denominator on one side can be moved to the numerator on the other side.

Example 12.2 Are b and c proportional in $bc = k$?

Solution: b and c are neither on opposite sides of the equation nor are they present as a fraction. The variables represented by b and c are not proportional to each other.



Example 12.3 *Are q and r proportional in $q = r + k$?*

Solution: Although q and r are on opposite sides of the equation, another term has been added. The variables represented by q and r are not proportional to each other.

Exercise 12.4

12-14 Given the following equations, which ones show that f and g are proportional to each other.

a. $f/g = q$; b. $q = f/g$; c. $f + g = q$; d. $fg = q$

12-15 Given the equation $z = fm$, are z and m proportional to each other? How do you know?

12-16 Given the equation $z = fm$, are f and m proportional to each other? How do you know?

12-17 In the following equations, each symbol at the left side is a constant. State whether or not the other two variables in each equation are proportional to each other.

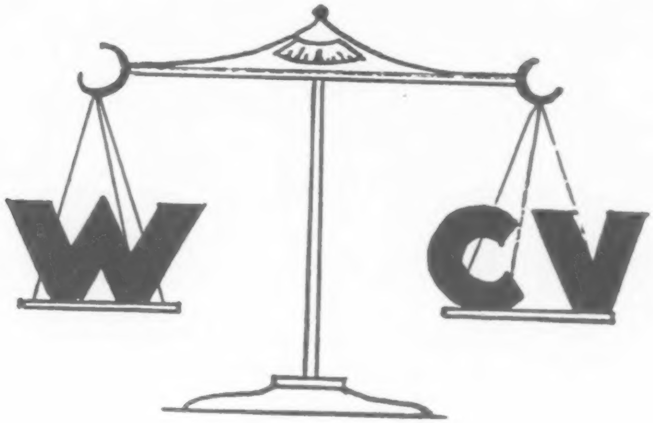
a. $F = ma$; b. $d = c/t^2$ c. $q = yx$; d. $z = a/b$

12-18 In the following, state whether the two variables in each equation are proportional to each other. In each equation, **k** is a constant.

a. Distance, **d**, that a car travels in time, **t**, where $\mathbf{d} = \mathbf{kt}$.
b. Distance, **d**, that an object falls in time, **t**, where $\mathbf{d} = \mathbf{kt}^2$.
c. Concentration of solid, **C**, dissolved in a volume of solution, **V**, where $\mathbf{CV} = \mathbf{k}$.
d. Weight of solid, **W**, dissolved in a volume of solution, **V**, where $\mathbf{W} = \mathbf{kV}$.
e. People standing, **P**, and people sitting, **p**,in a room with 40 seats where $\mathbf{P} + \mathbf{p} = \mathbf{k}$.

12-19 In the following equations, state whether y and x are directly proportional to each other when everything else is held constant.

a. $\frac{y}{x} = c$; b. $y = kx + b$; c. $\frac{y^2}{x} = k$; d. $z = y/x$; e. $yx = k$



Section 12.5 ORGANIZED KNOWLEDGE

When two variables can be described as proportional to each other, then we know much about the relationship. All sorts of things about the relationship is said in just those few words. How convenient that is!

Many relationships in nature are proportional. Each time, the phrase *proportional* or *directly proportional* means that whenever one of the variables changes by any multiplier, the other variable changes by the same multiplier, AND that the two variables may be described by the equation, $y = kx$. One description, proportional, can easily be applied to many cases.

This is one of the great strengths of science, to be able to take many different observations and to arrange them so that they can be described by one simple statement. The massive jumble of facts becomes orderly. The human mind can deal with the orderly arrangement of facts and can creatively build ideas about them.

Review, Chapter 12

Fill in the blank in the following.

1. When two variables are proportional to each other, their Per Fractions are always ______________________________.

2. When two variables are ______________________ , they both change by the same multiplier at the same time.

3. The following describe proportional variables. Fill in the blanks.

a. $\frac{50\ \text{mL}}{\text{bottle}}$, $\frac{\boxed{}}{3\ \text{bottles}}$

b. $\frac{15\ \text{nuts}}{3\ \text{candies}}$, $\frac{\boxed{}}{\text{candy}}$

The following are multiple choice questions.

4. Which of the following describes a direct relationship but not a proportional relationship?
   a. 2 twinkies/pack; 12 twinkies/6 packs
   b. 32 m/s; 96 m/3 s
   c. 10 players/team; 30 players/2 teams
   d. 14 g/pill; 7 g/2 pills

5. Proportional variables may be expressed as Per Fractions.
   a. true   b. false

6. Some Per Fractions used in everyday consumer relationships are not proportional.
   a. true   b. false

7. At the candy store, 5 sticks of gum cost 35¢. Seven sticks cost 49¢. This example illustrates
   a. a Per Fraction
   b. the Per One Rule
   c. proportional variables
   d. all of the above

8. Which of the following is another form of the equation, y = kx?
   a. $k = \frac{y^2}{x}$;   b. y/x = k;   c. y + x = k;   d. yx = k;   e. none of these

9. Which of the following does NOT show two variables which are proportional?
   a. 100 cm/m
   b. length x width = k
   c. 1 day/24 hours
   d. 12 inches = 1 foot

10. Given the equation y = kx where k is constant, which of the following choices is true?
   a. If y increases, k decreases.
   b. If y increases, k increases.
   c. If y increases, x increases.
   d. If k increases, x decreases.

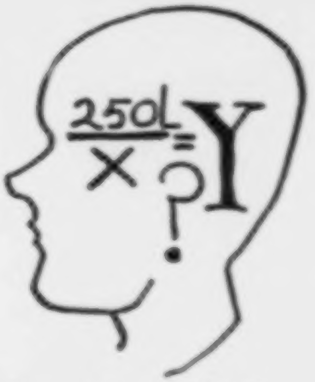
11. Which two variables are proportional in the speed equation when speed is constant?
   a. speed and distance
   b. distance and time
   c. speed and time
   d. there are no proportional variables in the speed equation

The following questions require a short answer.

12. The mass of a sample of silver changed from 5 g to 15 g. By what multiplier must its mass change?

13. The volume of a sample of sugar changed from 15 mm^3 to 5 mm^3. By what multiplier must its mass change?

14. Given oranges sold 30 to a basket. If the number of oranges changes by a multiplier of *q*, by what must the number of baskets change?



15. Which ones of the following illustrate proportional variables?
    a. $\frac{10\text{ miles}}{2\text{ hrs.}}$, $\frac{30\text{ miles}}{6\text{ hrs.}}$
    b. $\frac{50\text{ km}}{2\text{ hrs.}}$, $\frac{75\text{ km}}{4\text{ hrs.}}$
    c. $\frac{7\text{ g}}{2\text{ mL}}$, $\frac{42\text{ g}}{12\text{ mL}}$
    d. $\frac{5\text{ cm}}{2\text{ s}}$, $\frac{15\text{ cm}}{3\text{ s}}$

16. a. As the mass of a substance increases, how does its volume change quantitatively?
    b. What kind of a relationship is this?

17. Given a Per Fraction whose units are cm/s, identify the two variables that are directly proportional to each other.

18. Given a Per Fraction whose units are cupcakes/package, identify the two variables that are directly proportional to each other.

19. Given the equation, r = st
    a. are r and s proportional to each other when t is held constant?
    b. are r and t proportional to each other when s is held constant?
    c. are s and t proportional to each other when r is held constant?

20. Given the equation, $\frac{y}{z} = f$ where f is a constant, state what the question mark stands for in the equation $\frac{?y}{?z} = f$.

21. Given the equation, y = kx where k is constant, how does x change when y becomes 1/80 of what it was before?

22. Given the equation, yx = k, does x become 10 times as big when y becomes 10 times as big?

23. Given that each bar of soap has a mass of z grams. What is the mass of 20 bars?

24. Is the statement, "All proportional variables are directly related," true or false?

25. Is the statement, "All directly related variables are proportional," true or false?

For questions 26 to 30, state whether a and b are directly proportional to each other when all else is held constant.

26. ab = c;
27. bc = a;
28. $\frac{a}{b} = c$;
29. a = b + c
30. ac = b

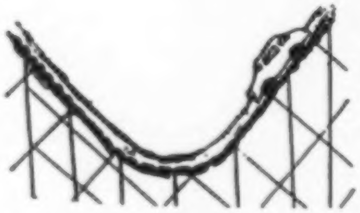
13
FORCE

In the preceding chapters, some of the mathematical tools that are available to help understand nature have been examined. Now, they will be helpful in studying natural relationships. This chapter will focus on motion and how it is caused. We are already familiar with one helpful equation which applies to motion, the equation for speed.

*Activity 13.1 FORCE AND MOTION, A Thought Experiment

In a thought experiment, you draw upon your past experience to see if you can make predictions. The following will ask some questions after which you will be asked to make a hypothesis.

Imagine a toy track on your desk built between two little hills, like a section of a roller coaster. The track is made of plastic and is not very smooth. An inexpensive toy car with small thin plastic wheels is set on the tracks at the top of one hill and is allowed to coast down to the bottom and up again.



Questions

1. Do you think the car will coast all the way up to the top of the other side? Explain.
2. Suppose you replace the toy car with a car of equal mass with ball-bearing wheels and axle. Will it go as far as the car did before? Why?
3. Suppose you also replace the plastic tracks with smooth steel tracks. Will the car with ball-bearing wheels go higher up the hill than it did before?

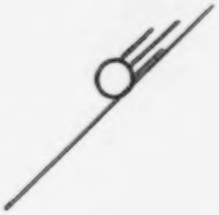
Hypothesis: Write your prediction for what would happen if the car's wheels and axle turned with perfect smoothness and if the car rolled down and up a perfectly smooth track.

Section 13.1 GALILEO'S GREAT DISCOVERY ABOUT MOTION

Our modern understanding of motion began with Galileo (gal-ill-LAY-oh) (1564-1642), one of our first great scientists. Among his many experiments were some made with hard balls which were rolled down an inclined plane.

*A **PLANE** is a flat surface. An **INCLINED PLANE** is a tilted flat surface.*

Ramps and straight uphill or downhill roads are inclined planes.



Galileo set up two flat boards at an angle to each other, somewhat like an upright V. Then he released a heavy ball from the top of one. The ball went to the bottom and rolled partway up the other side before it fell back. Could he get it to roll up higher? Galileo tried making the sphere smoother; the ball traveled a little higher up than before. Galileo made the inclined plane smoother, too; the ball traveled a little higher up. The more Galileo smoothed and perfected all the surfaces, the farther up the ball rolled till it finally went to almost the same height as when it had started.

Galileo also rolled a ball down one inclined plane onto the floor. The more the surfaces were smoothed, the farther the ball rolled along the floor.

After thinking about the data, Galileo came to his historic conclusion. First, he theorized that, for the planes set like a V, if the surfaces on the ball and the two inclined planes could be made perfectly smooth, the ball would roll back and forth to the same height, on and on forever. Moreover, if the ball were rolled from the inclined plane onto perfectly smooth ground, it would travel onward forever.

Do you really believe that the ball would roll on forever?

Of course, there is no perfectly smooth ground on the earth so we can't tell if the ball would keep going forever. Yet, we do know that a ball or a hockey puck goes much further on ice than it does on the ground.

The ground exerts friction on any object moving on it. The smoother the ground, the less the friction but some is always present. Friction acts to slow a moving object. Eventually, friction brings any moving object on this earth to a halt, and that is why we never see an object on earth moving forever. Wherever there is motion in our world, there is also friction to slow it down. We will talk more about friction later in this chapter.

Galileo had made a brilliant mental jump from what he was seeing to what he could imagine. His theory is now believed by all scientists. If a perfectly round sphere could be rolled onto a perfect road, it would travel along the road forever. If there were a perfect ice-skating rink which extended around a frictionless world, a person on it could be pushed once to skate around the world without any further effort.

There is at least one place where we can actually see Galileo's idea strongly supported, where motion takes place with no friction. In airless outer space, the planets move in their paths around the sun endlessly on and on and on.

Exercise 13.1

13-1 a. Discuss how an ice hockey puck illustrates Galileo's discovery.
b. Why does a moving puck on ice eventually slow down?
c. Name one famous person who lived during Galileo's lifetime.

Section 13.2 NEWTON'S FIRST LAW OF MOTION

The next great step in the study of motion was made by Isaac Newton (1642-1727), born the year that Galileo died. Newton started thinking about motion in terms of force.

A ***FORCE*** *is a push or a pull.*

Galileo had said that objects would continue to move in a straight line at the same speed forever if nothing stopped them. Newton built upon this to state his Three Laws of Motion.

Newton realized that a force is necessary to start an object moving, to change its velocity (to speed it up, slow it down, or turn it), or to stop it. In modern language*, Newton's First Law of Motion says:

> **An object stays at rest or moves**
> **with unchanged velocity unless**
> **a force acts upon it.**

Galileo's rolling spheres on the ground are examples of objects moving with unchanged speed until a force acts on them to slow them down. As another example of Newton's First Law, picture to yourself what happens to you when you ride in a car and the car stops suddenly. You do not stop. You continue to move forward in accordance with the First Law of Motion because the braking force was exerted on the car, not on you. That's why it is so important to wear a seat belt. The seat belt exerts a force on you that opposes your motion and stops it.

Note that the force in the First Law must be an unbalanced force.

An ***UNBALANCED FORCE*** *is a force which is not cancelled by a force opposing it.*

In a tug-of-war, for example, the force is unbalanced when one team pulls harder than the other. The extra, unbalanced force pulls the other team over. If the forces are balanced, neither team can be budged out of place. An unbalanced force always causes a change in motion.

Since friction causes moving objects to slow down, friction must act as a force.

The tendency of an object to stay in place or to keep moving at the same speed is called ***INERTIA*** *(inn-ERR-sha).*

Inertia is a property of mass. The greater the mass, the greater its inertia. Newton's First Law is sometimes called Newton's Law of Inertia. Because of the inertial property of mass, a push or a pull is necessary to change the motion of an object.

---

*In Newton's own words translated from the Latin in which he recorded his work, the First Law says, "Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by a force impressed on it."

Exercise 13.2

13-2 A car rolling along a level road with its motor off gradually slows to a halt. Did a force act upon it? If so, what was the force?

13-3 Jessica is driving a bumper car at a carnival. Someone comes up in back and bumps her car so that it is moving faster. Is the bump a force? Is it a balanced or an unbalanced force? How can you tell?

13-4 A car is parked on a hill. The car would move downhill if it weren't for the brakes on the car.

- a. Is the brake exerting a balanced or unbalanced force? Explain.
- b. What is the name of the force that would pull the car downhill if it weren't for the brakes?

13-5 Use Newton's First Law to define a straight line.

13-6 Is inertia directly or indirectly related to mass?

Section 13.3 NEWTON'S SECOND LAW OF MOTION

The second of Newton's Three Laws deals with the relationships between force, mass, and acceleration.

The First Law says that an unbalanced force is required to change the motion of an object, whether its speed or direction. Any change in motion is an acceleration. Hence, a force is needed to produce an acceleration.

For example, a force needs to be exerted on a baseball by the bat to make a home run. A braking force is needed to get a moving car to slow down or to stop.

Newton produced an equation which shows the relationships between force, mass, and acceleration. Scientific equations can be used to calculate a quantity of one variable given the other quantities. Just as important is that they provide a quick way to show the relationships between the variables.

The equation, called Newton's Second Law, states the relationships between force, mass, and acceleration quantitatively as follows.

$$\boxed{F = ma}$$

where F = force (unbalanced), **m** = mass, and **a** = acceleration. Recall that F is the abbreviated form for quantity of force. The other symbols also refer to quantities.

We already know how to determine whether two variables in an equation are proportional to each other. Let us examine some of the relationships shown just by looking at this equation.

To help to see the relationships, the equation F = ma can be rearranged into several forms. For us, the important ones are

(1) $\frac{F}{a} = m$ and (2) $\frac{F}{m} = a$

**Q. 1 Based on equation (1) above, which two variables are proportional to each other?

**Q. 2 Is it correct to say that the force exerted on a mass is directly proportional to the acceleration produced?

**Q. 3 Which other two variables are proportional to each other according to Newton's equation?

**Q. 4 Does Newton's equation say that mass and acceleration are directly proportional to each other?

Exercise 13.3

13-7 What is the form of Newton's Second Law which shows
  a. force and acceleration as a Per Fraction?
  b. force and mass as a Per Fraction?

13-8 State Newton's Second Law, as discussed above, in words.

Answers to Q's

Q. 1 *Force is proportional to acceleration (for a given mass).*
Q. 2 *Yes*
Q. 3 *Force and mass are proportional to each other (when acceleration is held constant).*
Q. 4 *No*

Section 13 . 4 EQUATIONS SHOW REAL RELATIONSHIPS: FORCE AND ACCELERATION

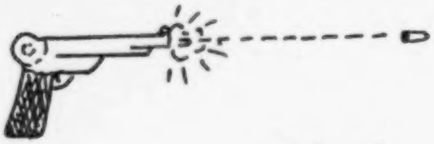
$\frac{F}{a} = m$
when "m" is constant

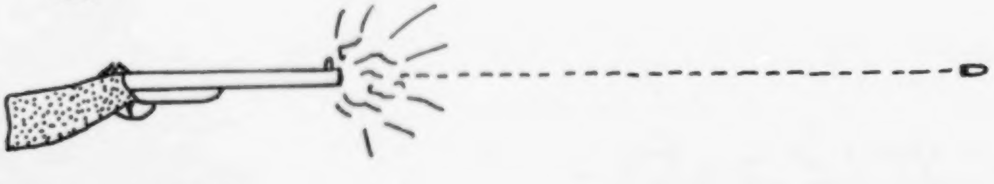
As we saw in the previous section, Newton's Second Law shows that the force exerted on an object is proportional to the acceleration produced. For our purposes, it is useful to just examine this relationship qualitatively.

What does Newton's Second Law say about the qualitative relationship between force and acceleration? Do they get bigger or smaller together, or does one increase while the other decreases?

Qualitatively, Newton's Second Law says that force and acceleration are directly related. The bigger the force on the same mass, the greater its acceleration. The smaller the force, the less the acceleration.

Let's consider some real examples of this. In each case, the mass is constant.





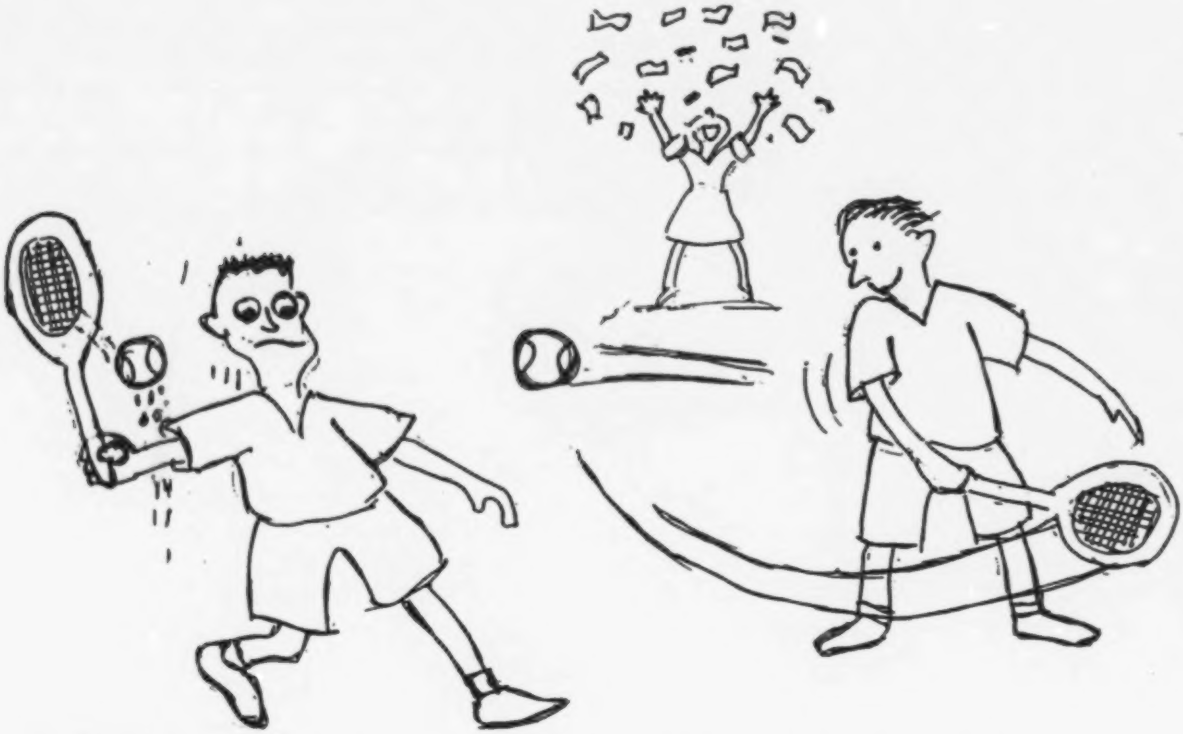
Bullet fired from a gun
Before firing, the bullet is at rest in the gun; the stronger the explosive force, the faster the bullet exits from the muzzle of the gun. The smaller the explosive force (F), the less the acceleration (a) of the bullet (constant m).

F ↑ a ↑; F ↓ a ↓

Hitting a tennis ball with a tennis racket
If you just poke lightly with your racket (even on the sweet spot) at an oncoming tennis ball, the ball will go from zero speed at your racket to a rather low velocity. However, if you really swing at the ball with great force, it can go from zero velocity at your racket to a very high velocity in the same elapsed time. The harder you swing (F), the greater the

acceleration (a). The less the force, the lower the acceleration of the ball. The mass (m) of the ball is constant.

F ↑ a ↑; F ↓ a ↓



Braking a car

When a car is moving and brakes are applied to stop it, the faster the car is moving, the harder you have to press on the brake to stop it in the same time. In this case, the force is used to slow down (decelerate) the object.

F ↑ a ↑; F ↓ a ↓

> If a car is moving at a low speed and the driver suddenly slams on the brakes as hard as possible, the car can be brought to a stop in a short time. The faster the car is going, the longer it will take to slow the car to a halt because the force is already at a maximum and can't be increased any more. (If the speed doubles, the car goes four times as far before it can be stopped. When speed triples, the car goes nine times as far before it can be brought to a stop.) This is one reason why it is so important not to drive too fast nor to tailgate the car in front of you.

Exercise 13.4

13-9 What has to be held constant to observe the relationship between force and acceleration?

13-10 A force acts upon an object with a mass of 2 kg.

a. When the force changes by a factor of 5, does the acceleration become bigger or smaller?

b. Suppose that the force becomes half of what it was, what happens to the acceleration?

13-11 A skipping stone is heaved horizontally over a lake. How can you get the same stone to have a greater acceleration?

Section 13.5 FORCE AND MASS

$\frac{F}{m} = a$

when "a" is constant

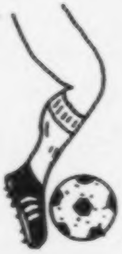
According to the Second Law, force and mass are proportional to each other when the acceleration is held constant. Qualitatively, this means that the force and the mass on which it operates are directly related. The engine used to push a train of four freight cars will have to exert twice as much force as for a train of two cars in order to get the same acceleration. When mass doubles, the force has to double is the acceleration is unchanged. Likewise, when mass decreases, the force needed to get the same acceleration must also decrease.

How can the acceleration be held constant when the force is increased? The only way to do this is to have the increased force act on an object with a bigger mass. Some examples of the force-mass relationship follow.

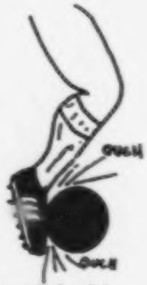
<ins>Soccer ball</ins>

Which would you rather kick, a soccer ball or a lead ball just as big?

It is much easier to kick a soccer ball than a lead ball. The much greater mass of the lead ball means that a much greater force is needed to get even a small acceleration. Much less force is needed with a soccer ball for the <ins>same acceleration</ins>.



soccer ball



lead ball

<ins>Racing car</ins>

Racing cars are made as lightweight as possible. The greater the mass of the car, the more powerful the engine must be (the greater the force) to produce the <ins>same acceleration</ins>.

<ins>Truck brakes</ins>

Trucks need much more powerful brakes than do cars because the force needed to slow down a heavy truck (negative acceleration) is much greater than the force needed to slow down the lesser mass of a car.

Exercise 13.5

13-12 Which requires more force to get the same speedup, a golf ball or a ping pong ball? Why?

13-13 Given that a force acts upon a mass of 12 kg. Does the force needed become bigger or smaller when

a. the 12 kg mass is exchanged for a 120 kg mass?
b. the 12 kg mass is exchanged for a mass one-fourth as big?

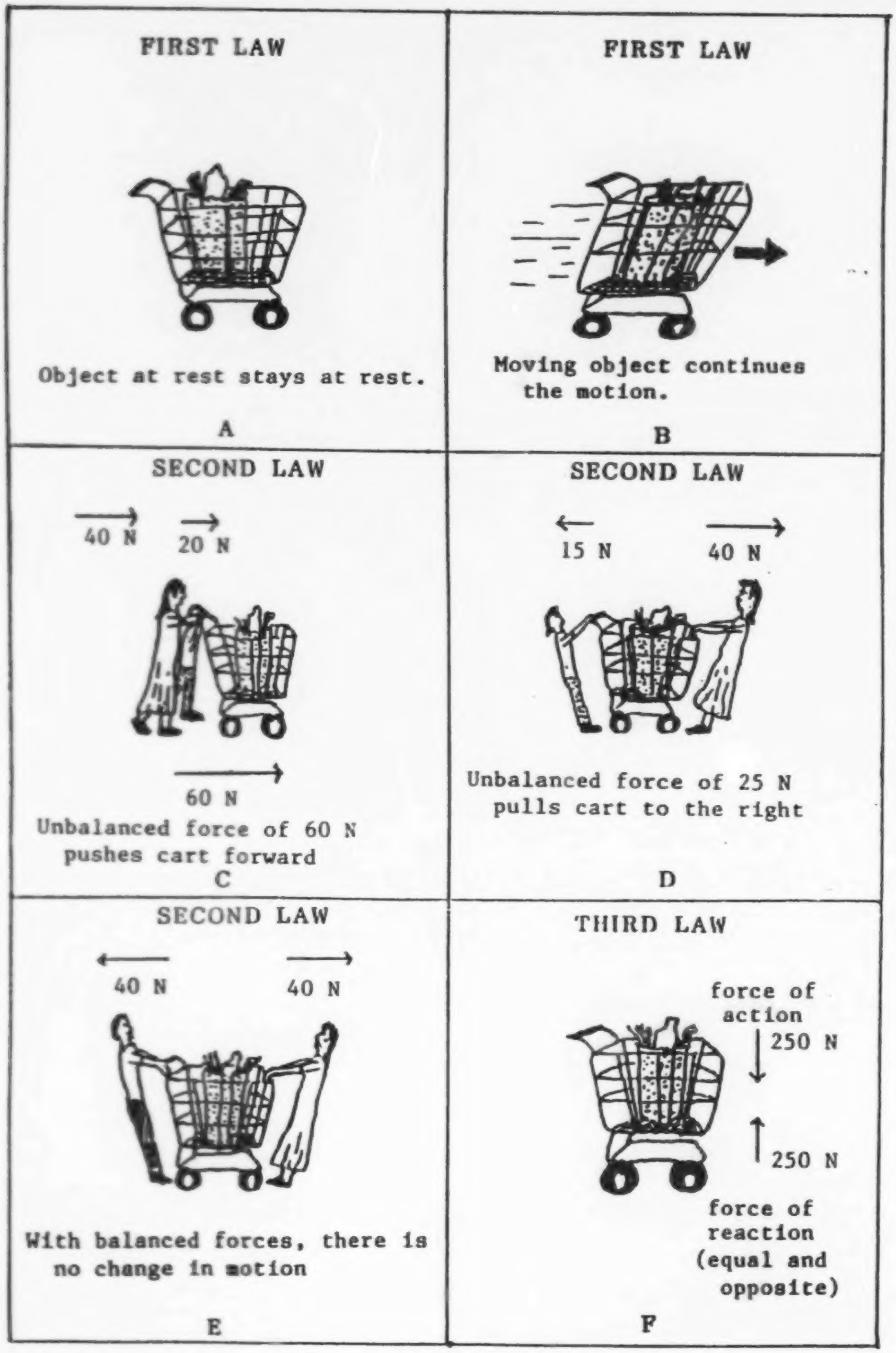

FIRST LAW
Object at rest stays at rest.
A
FIRST LAW
Moving object continues the motion.
B
SECOND LAW
40 N
20 N
60 N
Unbalanced force of 60 N pushes cart forward
C
SECOND LAW
15 N
40 N
Unbalanced force of 25 N pulls cart to the right
D
SECOND LAW
40 N
40 N
With balanced forces, there is no change in motion
E
THIRD LAW
force of action
250 N
250 N
force of reaction (equal and opposite)
F

Figure 13.3 Newton's Three Laws

Optional: **Section 13.6** RELATIONSHIP BETWEEN MASS AND ACCELERATION WHEN FORCE IS CONSTANT

F = ma

when "F" is constant

Imagine heaving a bowling ball and a billiard ball with the same force down a bowling alley. Which one will go faster? The billiard ball will certainly move faster than the bowling ball.

**Q. 1 Is the relationship direct or inverse between the mass of the ball and the acceleration produced when the same force is applied?

Does the equation for Newton's Second Law show this inverse relationship? To answer, consider the table directly below. Assume that the correct units are used for the quantities; only numbers are shown.

F	=	m	x	a
12		2		6
12		4		3
12		6		?

**Q. 2 What is the missing number for acceleration in the above?
**Q. 3 As the values for mass increase, what happens to the values for acceleration?

Hence, Newton's Law agrees with our own experience and tells us that the relationship between mass and acceleration for a constant force is indirect.

Exercise 13.6

13-14 Given a golf ball and a bowling ball, which moves faster if pushed with the same force? Why?

13-15 Given an equation of the form k = ma, what is the relationship between **m** and **a** if **k** is held constant?

13-16 Given the equation, z = xy, what is the relationship between
- a. z and y?
- b. x and y?
- c. z and x?

Answers to Q's

Q. 1 We see that as mass increases, the same force produces a decrease in acceleration. The relationship is inverse (or indirect).
Q. 2 The missing number is 2.
Q. 3 The values for acceleration decrease.

Section 13.7 EQUATIONS; A FORM OF ORGANIZATION

We have seen that the organization of our knowledge of relationships in nature can be of two broad types, those which involve some kind of arrangement of properties (classification, ordering, and modeling) and those which involve two variables that change at the same time.

Equations, such as the ones for speed, density, and Newton's Second Law, are very elegant and exact ways to describe the second type, the relationships between two variables that always change at the same time. Each equation provides a shorthand mathematical description of relationships between variables which is quantitative.

Only a few symbols and an equals sign are needed to describe such relationships quantitatively and completely. It is truly a wondrous way to organize such knowledge.

Exercise 13.7

13-17 How is an equation a tool for the organization of knowledge?

Section 13.8 NEWTON'S THIRD LAW

Newton's Third Law is surely one of the most perceptive in science yet it may not be immediately obvious to you. To get an idea of what this Law says, picture yourself as you most probably are at this moment, that is, sitting in a chair. How come you don't fall right through the chair?

Did you say that the chair is holding you up? Newton would agree with you; he would say that the chair is pushing you up. Gravity is pulling you downward upon the chair. The downward pull of gravity and the upward push of the chair are balanced forces; hence, you stay in place. If the chair happened to have been poorly made and suddenly collapsed so that it was no longer pushing you upward, you would most certainly fall to the floor. According to Newton, all forces occur in pairs. In his own words, Newton's Third Law states:

> **"To every action there is always opposed an equal reaction."**

That is to say, whenever you push on something, that something pushes back at you. In fact, you can't push on it unless it can push back. If you make the action, the other object makes the reaction. You push it in one direction and it pushes you in the opposite direction.

Activity 13.2 A BALLOON JET

Purpose: to observe an example of Newton's Third Law

Materials: a drinking straw, a balloon, and a twist-tie or rubberband

Procedure:

1. Obtain the materials.
2. Attach the balloon tightly to the end of the straw. Don't close the straw.
3. Blow up the balloon through the straw and cap the straw with your finger. Hold the balloon up high and let go.

Conclusion: How do your observations illustrate the Third Law?

Activity 13 . 3 NEWTON'S LAWS

Purpose: to observe Newton's Second and Third Laws in action
Materials: two skateboards.
Procedure:
This is a group experiment in which the class observes two students carrying out the experiment.

Step 1:
1. Two students stand on skateboards with the long sides arranged side by side and with the students facing in opposite directions.
2. One student grasps the hand of the other and pushes the other away.
3. Compare the direction of motion for each.

Step 2:
1. Again, two students stand as in the start of Step 1.
2. The students move to arm's length from each other.
3. One student pulls the other over and past.
4. Compare the direction of motion for each.

Step 3:
1. One student sits down in a chair.
2. The other student grasps the sitter's hand and tries to pull the sitter up out of the chair while the sitter resists.
3. After a few seconds, the student stops the pulling.
4. Now, the standing student grasps the sitter and tries to pull the sitter up out of the chair while the sitter cooperates.
5. The student doing the pulling should compare the strength of the forces needed with and without cooperation.

Questions

Q. 1 In Step One,
  a. one student pushed on another. What effect did this have on the student doing the pushing?
  b. compare the force on the student doing the pushing to the force on the student who was pushed.

Q. 2 In Step Two,
  a. one student pulled on another. What effect did this have on the student doing the pulling?
  b. compare the force on the student doing the pulling to the force on the student who was pulled.

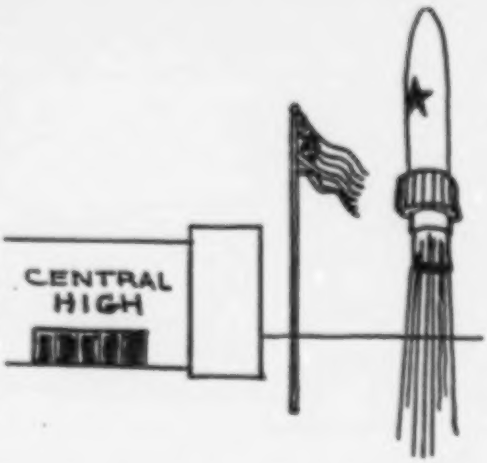
Q. 3 According to Steps One and Two, when Object X exerts a force on something, what happens to Object X?

Q. 4 Based on Step Three, what is necessary for a force to be exerted on something?

Some other examples of Newton's Third Law follow.

Walking

A familiar example of the Third Law is walking. In order to walk, you press down and backward, at an angle, onto the ground. The ground pushes back at you and propels you forward. That's what makes it possible for you to walk. If the ground is mushy so that it can't exert a force on you, you can't push on it. Instead, your foot goes into the mush.



Rockets and jet planes
Newton's Third Law is demonstrated when rockets are propelled into outer space. The gases shooting out at the back push the rocket forward. A jet plane flies forward when air is pushed out the back of it.

**Q. 1 Does this mean that when you lean on a wall, the wall leans on you?

Exercise 13.8

13-18 A book is on a table. State how the book and the table illustrate Newton's Third Law.

13-19 How does an oar cause a boat to move? In which direction does the oar push? In which direction does the boat move?

13-20 How do an automobile's wheels going along the ground illustrate Newton's Third Law?

13-21 An athlete sitting in a wheelchair tosses a basketball forward. What happens to the wheelchair?

Answer to Q
Q. 1 Yes. Otherwise, you would fall forward.

Activity 13.4 THE SECOND AND THIRD LAWS

Purpose: to illustrate Newton's Second and Third Laws

Materials: balloon, flexible straw, twist-tie or rubberband.

Procedure

1. Obtain the materials.
2. Insert the short end of the flexible straw into the balloon and tie it tightly around the neck with the twist-tie or rubberband.
3. Bend the straw to a right angle.
4. Inflate the balloon and stopper the outside end of the straw with your finger.
5. Lower the balloon to the ground, and release it.

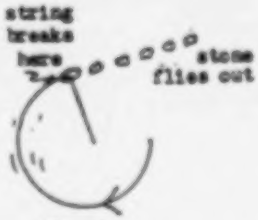
Conclusion: Connect your observations to Newton's Laws in as many ways as possible.

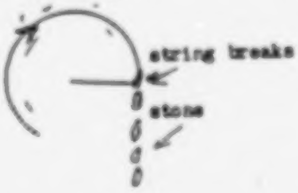
Optional: Section 13.9 CURVED MOTION

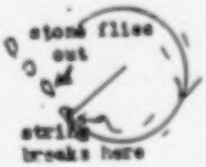
What makes an object move in a curved path? It has to be pushed or pulled around; otherwise, it would move in a straight line.

An object moving in a circle is changing its direction all the time. If you are on a merry-go-round, for example, you keep seeing something different all the time as you go around because you keep changing the direction you are facing.

Imagine that you are whirling a stone on a string around your head. You let go of the string.







**Q. 1 Does the stone continue to whirl around your head? What happens to the stone?

When you let go of the string holding the stone, you stop exerting a force on it; only while you pull on the string can the stone travel in a circle. As soon as you let go, the stone and string fly off in the direction the two were going at that instant.

The stone and string exert a force on your hand which you can feel as they pull on your hand. Your hand, in turn, continually exerts a force on the string to the stone to change its direction. Can you get the stone to move in a circle without moving your hand? Try it.

This agrees with Newton's Laws since any change in the direction of a moving object is an acceleration. A force is always required to produce an acceleration.

In an automobile, any change in direction is made by turning the car's wheels. As the wheels turn, they keep pushing against the ground in different directions, thereby changing the direction of the push back from the ground. If the road is banked, it causes the car to turn by exerting a force at an angle to the horizontal against the wheels.

**Q. 2 A train rolls around a wide curve on the rails. What causes the train to move in a curve? (Hint; trains do not have steering wheels.)

Exercise 13.9

13-22 All the planets move in loops around the sun. Does this mean that the sun exerts a force on them?

Answer to Q's

Q. 1 No, the stone does not continue to go round and round. Instead, it shoots off in a straight line in whatever direction it was going the instant you let go.

Q. 2 The rails are curved and may be banked. When the train pushes on them, they push back at the train. The direction at which they push back is constantly changing which keeps forcing a change in the direction of the train.

Section 13.10 THE NEWTON, UNIT OF FORCE

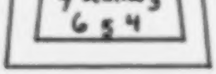
The unit for force comes from Newton's Second Law, $F = m \cdot a$. The unit for m is kg and for a is $\frac{m}{s^2}$.

Putting these into the equation, $F = ma$, the unit for F is $\frac{kg \cdot m}{s^2}$.

This is a complicated unit to use. Scientists have abbreviated this to N, the newton, named after the famous scientist.

$$1\ N = 1\ kg \times \frac{1\ m}{s^2}$$

Hence, for $F = m \cdot a$,
the corresponding units are $N = kg \times \frac{m}{s^2}$



1 small apple weighs 1 newton

The measurement label for force is in newtons any time that the mass is measured in kilograms and acceleration is in meters per second squared.

Exercise 13.10

13-23 a. What does a newton equal in measurement units of kilograms, meters, and seconds?

b. A unit exists for force called a dyne. A dyne is the force needed to accelerate a mass of one gram by one centimeter per second each second. What does one dyne equal in measurement units of grams, centimeters, and seconds?

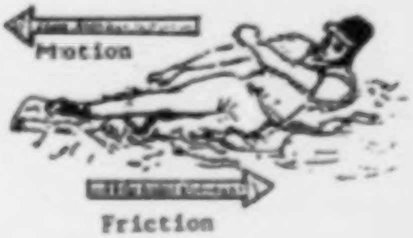
13-24 Use the four steps for the problems in a. and b. below.

a. Given that a force is accelerating a mass of 15 kg by 6 meters per second each second. Calculate the force in newtons.

b. Given that a force is accelerating a mass of 12 500 g by 10 m/s^2. Calculate the force in newtons.

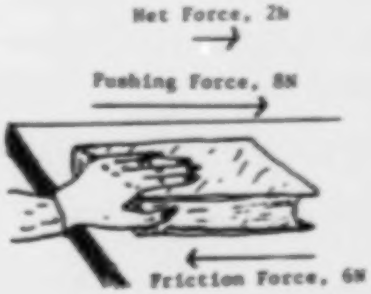
c. Are these forces balanced or unbalanced?

Section 13 . 11 FRICTION



If a force produces a change in velocity, how come you have to keep pushing on a supermarket cart just to keep it going at the same speed in the same direction? The answer can be stated in one word, friction. Friction is present whenever two surfaces meet. Friction always acts as a force to slow down motion.

When an object is stationary, any attempt to get it to move on our world is opposed by friction. *Stationary friction, also called* ***static friction****, acts as a force to keep objects from moving when a force is applied.*



To get objects to move when friction is present, a force is needed first to overcome the static friction and then to get the object to move (to accelerate it). When objects are moving, friction is generated wherever the object touches any material, such as the ground or the air. The friction slows the motion. (The lost motion changes into heat and warms the object.) To keep a supermarket cart moving at a steady speed, enough force must be exerted on it to balance the opposing force of friction. As long as the force of friction is exactly balanced, the cart keeps moving at the same speed it had before in accordance with the First Law.

It is because of friction that a driver has to press on the gas pedal to keep feeding more gasoline to the engine while the car is moving. Without friction, a car would just keep moving at the same velocity without needing any more gasoline.

On the other hand, friction is necessary to start the car moving. In order to be pushed forward, the car has to push against the ground. Without friction, it cannot push. Friction is good as well as bad.

Friction is greater on a rough surface than on a smooth one. To help reduce friction,

(1) surfaces can be made smoother.

(2) lubricating (LOO-bruh-kay-ting) oils can be placed between the surfaces where possible; the oils help one surface to slide easily over the other.

(3) solid objects moving through liquid or air can have the surfaces streamlined to decrease the exposed surface and to prevent air or liquid turbulence.

Exercise 13.11

13-25 What is the difference between static friction and moving friction?

13-26 Does friction act upon an airplane in motion in the sky? What produces the friction?

13-27 Suggest two ways to reduce friction between an object moving in contact with another one.

****

CHAPTER 13 REVIEW

Match the units on the left to the term on the right.

1. g
2. N
3. $\frac{m}{s}$
4. $\frac{m}{s^2}$
5. cm^3
6. g/mL

a. speed
b. acceleration
c. density
d. force
e. mass
f. volume

Match the term at the left to the formula at the right.

7. density
8. velocity
9. force
10. acceleration
11. mass

a. F/a
b. $\frac{\text{change in velocity}}{\text{change in time}}$
c. ma
d. m/v
e. d/t

The following are multiple choice questions. Select the best choice to answer each.

12. The inertia of a body tends to cause the body to
    a. speed up
    b. slow down
    c. resist any change in motion
    d. stop

13. When a supermarket cart is pushed along a level floor at a uniform speed of 10 m/s, the force is needed to
    a. accelerate the cart to a greater speed.
    b. overcome friction.
    c. lift the cart.

14. From Newton's Second Law, it follows that if force is increased while the acceleration remains constant, the force must have acted
   a. upon a more massive object.
   b. upon a less massive object.
   c. upon an object with the same mass.

15. For a given mass, the acceleration and the unbalanced force that produces the acceleration are
   a. equal.
   b. neither directly related nor directly proportional.
   c. directly proportional but not directly related.
   d. directly related but not directly proportional.
   e. directly related and directly proportional.

16. A force is applied to a space ship in outer space. After the force is removed, the space ship
   a. moves with constant acceleration.
   b. moves with constant velocity.
   c. moves with decreasing acceleration.
   d. moves with decreasing velocity.

17. The force in newtons required to accelerate an object whose mass is 4 kg by 200 km/s each second is
   a. 50; b. 50 000; c. 800; d. 800 000; e. 1000

18. Force can be measured in units of
   a. $\frac{kg \cdot m}{s^2}$; b. $\frac{N}{s}$; c. $\frac{kg \cdot m^2}{s}$; d. $kg \cdot m$; e. $\frac{kg}{s^2}$

For Items 19 to 22, each statement best illustrates one of the following choices. Select the best choice for each statement.
   a. Newton's First Law
   b. Newton's Second Law
   c. Newton's Third Law
   d. none of Newton's Three Laws

19. A car speeds up under a steady force.

20. When a horse stops suddenly, its rider flies over the horse's head.

21. When a shotgun is fired, it exerts a kick backwards called a recoil.

22. Heavier cars must have more powerful engines if they are to have the same pickup (acceleration) as lighter cars.

23. The natural law that an object continues to move at the same speed forever if nothing stops it was first discovered by
   a. Galileo.
   b. Lavoisier.
   c. Newton.
   d. Democritus.

24. An equation is made up of symbols which represent
    - a. names of related variables and constants.
    - b. numbers of related variables and constants.
    - c. quantities of related variables and constants.
    - d. letters for related variables and constants.

25. When the force acting upon a mass changes to six times as much as before, the acceleration produced
    - a. increases.
    - b. decreases.
    - c. doesn't change.

26. In order to produce the same acceleration for a larger mass than before, the force must
    - a. increase.
    - b. decrease.
    - c. remain unchanged.

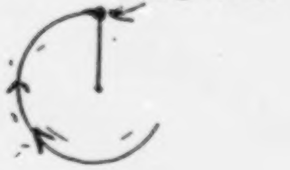
The following require short answers.

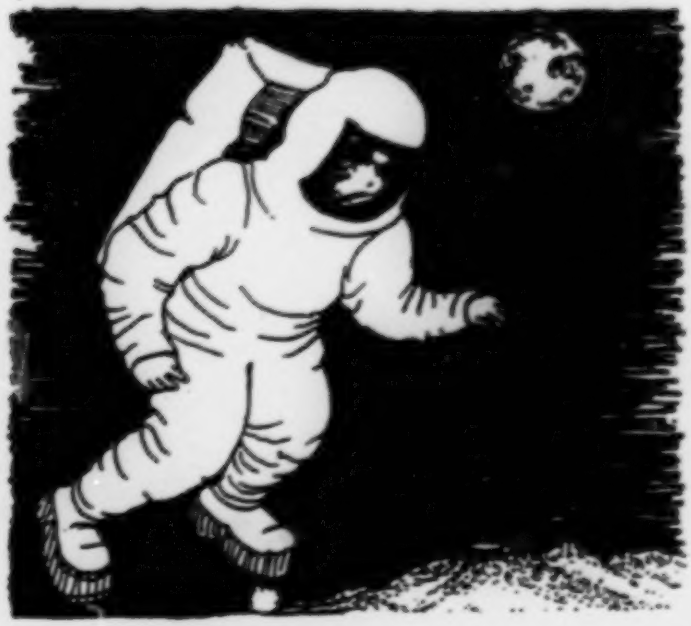
27. A force of 10 newtons has to act on a moving object to keep it going at a uniform speed.
    - a. How can you tell that a frictional force is operating?
    - b. How big is the frictional force?

*28. Given an equation of the form, $F = ma$,
    - a. what is the relationship between m and a?
    - b. as a increases, what happens to m if F stays the same?
    - c. as F increases, what happens to a if m is constant?

*29. Given an equation of the form, $W = Fd$,
    - a. what is the relationship between F and d?
    - b. as F increases, what happens to d if W stays the same?
    - c. as W increases, what happens to d if F is constant?

*30. a. Why does an object moving in a circular path always require a force acting on it?
    b. In the diagram below, in which direction does the object move if the string twirling it is suddenly cut off?





14
GRAVITY

Activity 14 . 1 FALLING

Purpose: to observe the relationship between the mass of an object and the speed of its fall
Materials: book, styrofoam block about same size and shape as book, wrapping paper, tape
Procedure:

Step 1: Wrap the book with paper and seal it. Do the same for the styrofoam block.

Step 2: Lift the styrofoam block in one hand and the book in the other. Hold them both so that the wide side is horizontal. Drop both from as high as you can to the desk top at the same time. Which one hit the table first? Record your observation.

Questions

Q. 1 If you dropped the styrofoam block and the book from as high as you can to the floor, which one do you think would hit first? Why?

Q. 2 According to this experiment, what is the relationship between the time of fall of objects and their mass, all else being the same?

Section 14.1 THE FORCE OF GRAVITY

Ever since the early history of humanity, people have tried to escape the effects of gravity. It was always a dream to be able to float above the ground or to be able to leap lightly into the air and soar away. But, gravity is everywhere upon the Earth. We can leap above the ground but we fall back. We are pulled down by the Earth's gravity.

GRAVITY is the force of attraction between any two masses.

Gravity
(1) is a property of any mass.
(2) is always an attractive force; it pulls both masses closer. On Earth, it accelerates any object down toward the ground.
(3) increases with mass.
(4) exerts a force which decreases with distance; on Earth, the force decreases as height above ground increases.
(5) can act through empty space.

Gravity exists throughout our universe. The planets, comets, moons, stars, and every object in the universe which has mass have a gravitational field which affects other masses.

We have studied the inertial property of mass. Inertia causes a mass to remain in place or to have unchanged motion unless an unbalanced force acts upon it. Mass also has a gravitational property; gravity causes it to exert a force on and to be attracted to other masses.

Exercise 14.1

14-1 What is meant by saying that gravity is a force?

14-2 Can a mass attract or repel another mass?

14-3 Is the relationship between the distance between two masses and the force of gravity between them direct or indirect?

14-4 Is it possible to remove the gravity from an object and transfer it to another object?

14-5 Distinguish between the inertial and the gravitational properties of mass.

Section 14.2 THE ACCELERATION DUE TO GRAVITY

The force of gravity causes objects to accelerate. On the Earth, the acceleration of any object, regardless of its mass, is the same. You saw this in Activity 14.1. Galileo is supposed to have dropped a cannon ball and a wooden ball simultaneously from the Leaning Tower of Pisa. The story says that the two objects hit the ground at the same time.

At the earth's surface, the acceleration due to gravity is 9.8 meters per second every second (9.8 m/s^2). Every second, an object falls 9.8 meters per second faster than it did before.

At the end of one second, it has a velocity of 9.8 m/s downward.
At the end of two seconds, it has a velocity of 19.6 m/s downward.
At the end of three seconds, it is falling at a velocity of 29.4 m/s, and so on.

No wonder it is so dangerous to fall from a height!

Exercise 14.2

14-6 For an object falling for 2½ seconds, which of the following choices is correct?
- a. the object is falling at a speed of 9.8 m/s.
- b. the object is falling at a speed between 19.6 m/s and 29.4 m/s.
- c. the object is falling at a speed of 19.6 m/s.
- d. the object is falling at a speed of 29.4 m/s.

14-7 What is the predicted speed of a falling object after four seconds?

14-8 Which should fall faster according to Section 14.2, a cannon ball or a cantaloupe?

Section 14.3 TERMINAL VELOCITY

Gravity exerts an attractive force that causes all objects near the Earth's surface to accelerate downward at 9.8 m/s^2. When a object falls in our atmosphere, the air exerts an upward force on the falling object to slow its fall.

The upward pressure of the air is called ***AIR RESISTANCE.***

The more surface an object presents to the air beneath it, the greater is the air resistance. A feather has a very large surface. Its air resistance is much greater than that of an object with the same mass but squeezed into a shape with a smaller surface such as a ball. In the air, a paper ball the same weight as a feather falls much faster than a feather.

As the speed of a falling object increases, its air resistance increases. Eventually, as the falling object continues to speed up, the upward air resistance balances the downward force exerted by the falling object. When this point is reached, does it mean that the object stops falling?

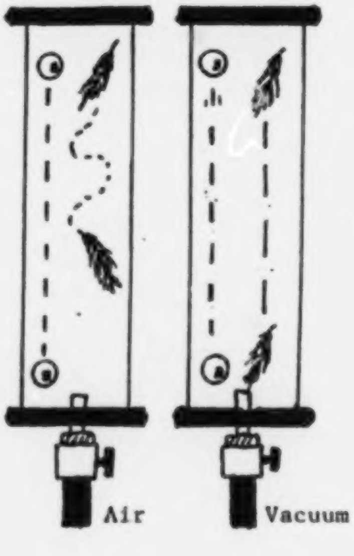
No, the object continues to fall. When the forces at its surface balance out to zero, the object continues to move in the same direction at the same speed that it had at the instant when the forces balanced. It obeys Newton's First Law. It keeps falling to the ground at a constant velocity.

The constant velocity reached when the air resistance equals the downward forces is called the ***TERMINAL VELOCITY.***

Unfortunately, by the time that terminal velocity is reached, the downward speed can be high enough to kill most living creatures on impact.

It is only in a vacuum (no air) that all objects keep falling with increasing speed on the Earth. In a vacuum, falling objects never reach terminal velocity.

In the air, a hammer falls much faster than a feather. This is not so in a vacuum. In 1971 while on the surface of the airless moon, David R. Scott, an Apollo 15 astronaut, held a feather in one hand and a hammer in the other. He dropped them both together. They landed at the same time. "How about that!" said Scott. "Mr. Galileo was correct."



Exercise 14.3

14-9 a. Which will fall faster in the classroom, a feather or a penny? Why?

b. Which will fall faster in a container from which all air has been removed, a penny or a feather? Why ?

14-10 Why is the terminal velocity of a falling object less with a parachute than without one?

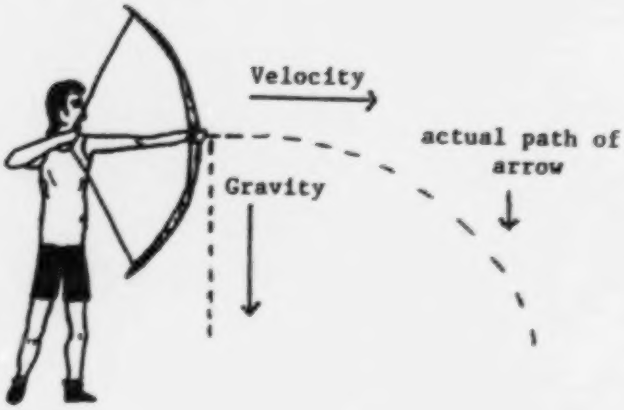
14-11 When an object reaches terminal velocity, what does this mean about the forces acting on it?

Section 14.4 COMPOUND MOTION

Picture a ball thrown straight out horizontally at shoulder height. Air resistance at this speed is so small that the ball can travel quite a distance horizontally. It doesn't because it is also falling. It travels outward at a steady speed but drops toward the ground (at accelerated speed) at the same time, and is stopped when it hits the ground.

What happens to the ball is a combination of horizontal speed and vertical fall. The name given to such *combinations of motion* is ***COMPOUND motion***. The motion of an arrow shot from a bow is another example of compound motion.

At any chosen height, it takes the ball the same time to hit the ground no matter how fast it is travelling horizontally. On the other hand, the faster the ball is thrown, the farther away it gets before it hits the ground.



**Q. 1 Suppose a bullet is fired horizontally at the same time that another bullet is dropped at the same spot. Which hits the ground first?

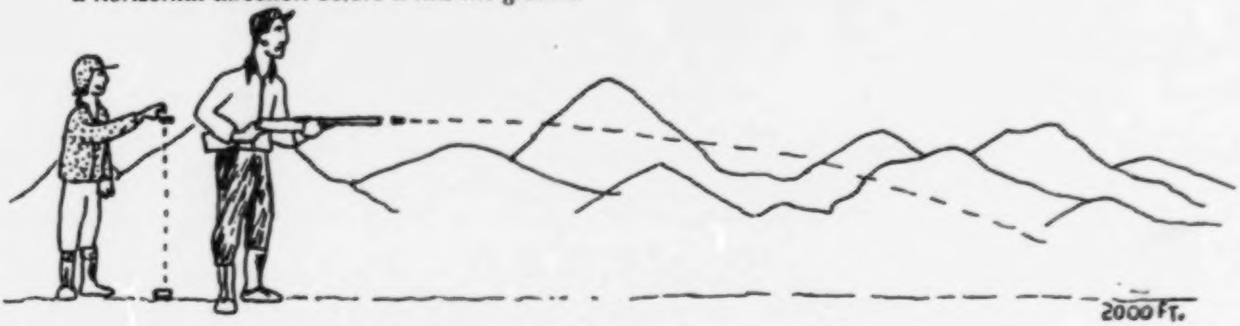
Exercise 14.4

14-12 A bullet fired horizontally from a gun has compound motion. After the bullet leaves the gun,

a. is the horizontal motion at a constant speed or is it accelerated?
b. is the vertical motion at a constant speed or is it accelerated?

14-13 A ball is dropped to the ground from the same height that a ball is pushed from the same spot horizontally. Which hits the ground first? Why?

Answer to Q
Q. 1 With no friction present, they both hit the ground at the same time. They will both stay in the air only as long as it takes for the bullets to fall to the ground; the time will be the same for both. The only difference is that the bullet that was fired will have traveled much further away in a horizontal direction before it hits the ground.



Section 14.5 WEIGHT

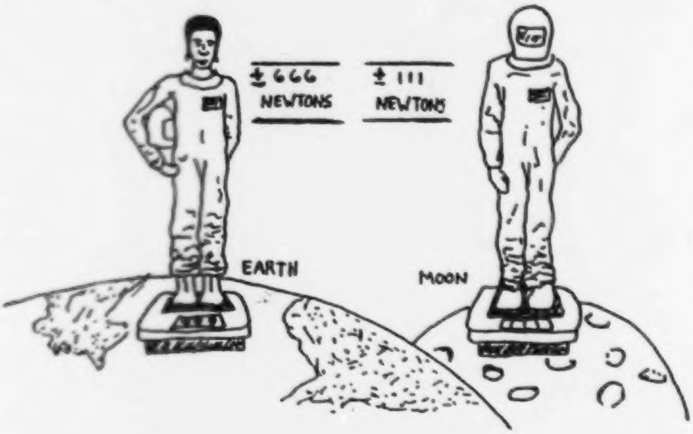
An object on a scale exerts a downward force on the scale because gravity is pulling it downward. The scale, in turn, pushes the object back up until the forces are balanced. The downward force exerted by the object is called its weight. An object has weight due to gravity.

***WEIGHT** is the downward force that an object exerts due to gravity.*

A mass of 1 kg is accelerated downwards by gravity at 9.8 m/s^2 so that it exerts a downward force of 9.8 N. (Since F = ma, F = 1 kg x 9.8 m/s^2 = 9.8 N.) Hence, a mass of 1 kg has a weight of 9.8 N. (A newton is approximately 1/4 lb.)

Weight is directly related to mass; weight increases with mass. On the other hand, weight is inversely related to height above ground; weight decreases with height above the Earth. As an object gets farther away from the Earth, its downward acceleration decreases and so does its weight.

The moon exerts a much smaller gravitational attraction than does the Earth because the moon has so much less mass. Hence, the moon gives falling objects a much smaller downward acceleration than does the Earth. Objects weigh about one-sixth as much on the moon as they do on Earth.



Mass and weight are not the same. Mass is a measure of the quantity of matter. Weight, on the other hand, is a force that depends upon the mass of the object and any mass near to it. An object has the same mass wherever it is, whether on earth, the moon, or outer space. A person with a mass of 68 kilograms weighs 666 N (150 lb.) at the surface of the earth. On the moon, that person weighs about 111 N (25 lb.) If the person stood on a scale in outer space, no weight would be recorded on the scale at all. The person would just float above the scale. The person's mass all along remains at 68 kilograms.

Exercise 14.5

14-14 For each of the following, state whether the relationship is direct, inverse, or there is no relationship:

- a. the weight of an object on earth and its mass.
- b. the weight of an object and its distance from the earth.
- c. the mass of an object and its acceleration due to gravity.

14-15 At the Earth's surface,

- a. which has a greater acceleration due to gravity, an object of 10 kg or an object of 20 kg?
- b. which has a greater weight, an object of 10 kg or an object of 20 kg? Explain in terms of F = ma.

Activity 14.2 EGG PACKING

Purpose: to drop an egg from a high location without breaking it

Materials: bag of materials.

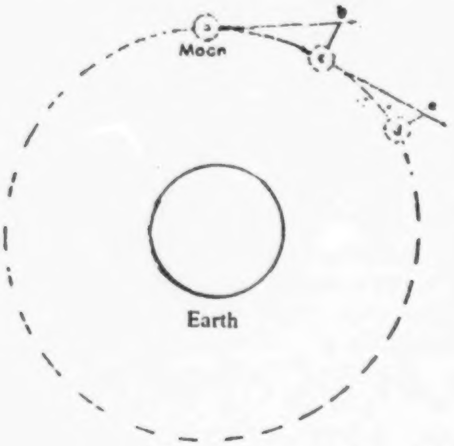
Procedure: You will be part of a team whose task is to drop an egg from a height without breaking it. To do this, you will need to wrap the egg in a protective covering. The materials for the covering are in the bag. You will lose credit for each one not used. At the end of the allowed time period, you must hand in your entry properly labeled plus all the materials left in the bag. During the next laboratory period, your entry will be tested.

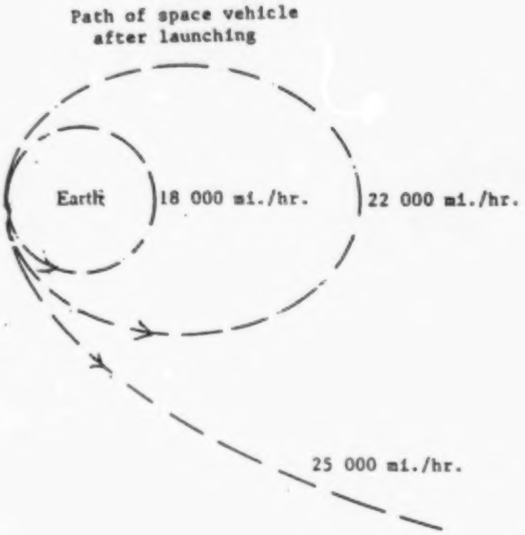
Optional: Section 14.6 ESCAPE VELOCITY

In 1957, the Soviet satellite, Sputnik I, became the first artificial satellite successfully launched into space. Since then, hundreds of satellites have been sent up, most of them by the United States and the Soviet Union. American spacemen have walked upon the Moon and brought back samples of its surface. The United States and the Soviets have both had great accomplishments in outer space and saddening tragedies as well. Humans have learned more about the planets in our system along with their moons in the past few decades than was learned in all the time before that.

But what holds the satellites up? Why don't they fall?

The answer is that the satellites orbiting the Earth are falling all the time. To picture this, consider our only natural satellite, the Moon, as shown in the diagram at the left, below.





The Moon is like the stone on a string in Section 13.9. Gravity is the invisible string pulling the Moon toward the Earth. If the Earth were suddenly removed, the Moon would just keep going in the same direction that it had been when the Earth vanished. The line between a and b in the diagram shows this. Since the Earth has not vanished, the Moon keeps getting pulled back toward the Earth (the line from b to c) moving in compound motion like a ball pitched straight out. The Moon travels so fast that it passes the Earth before it can fall to the ground following the path from a to d. And it keeps falling toward the Earth as it travels round and round and round.

Similarly, a satellite in orbit has to move fast enough to keep circling or it will fall to the Earth. If a satellite is launched with a speed of 18 000 miles per hour, it will be moving fast enough to go into orbit.

If the satellite reaches a speed greater than 18 000 miles an hour, its path will go much farther out and will turn into a loop (an ellipse). At 25 000 miles per hour, it will reach escape velocity. *At ESCAPE VELOCITY, an object launched from Earth has enough speed to completely depart from the Earth without returning.*

Since the moon's mass is much less than that of our Earth, its escape velocity is much smaller.

An astronaut on a satellite orbiting the Earth feels weightless even though the astronaut is being slightly accelerated toward the Earth by gravity. The astronaut feels weightless because everything on the satellite is falling at the same time. The astronaut, satellite, and everything on it are in free fall--nothing is stopping the fall.

If the astronaut stands on a scale, no weight is registered. This is because the astronaut and the scale are both falling alongside of each other. The astronaut, however, does have some weight due to the Earth's gravity. True weightlessness can come only when all gravitational fields acting on the object are balanced. The apparent weightlessness in orbit allows an astronaut to float in the cabin and sleep in the air but it also forces the astronaut to drink a liquid with a straw because the liquid can't be poured.

Exercise 14.6

14-16 How many years ago was the first successful artificial satellite launched?

14-17 What is the velocity needed to launch a satellite into orbit around the Earth? What is the escape velocity?

14-18 Does it take more or less fuel to launch a spaceship to the Moon from the Earth than to launch that same spaceship from the Moon back home to Earth? Why?

14-19 Why is an astronaut weightless in orbit but not on the Moon?

Chapter 14 Review

Vocabulary

compound motion
terminal velocity
gravity
weight
acceleration

Use each one of the vocabulary words or phrases from above just once to fill in the blanks in the following.

1. Constant speed of fail: ________________________

2. A downward force: ________________________

3. When an object moves both vertically and horizontally at the same time, this is described as ________________________ .

4. Attractive only: ________________________

5. Changing speed: ________________________

Applications

Select the single best choice from among each of the following.

1. The acceleration due to gravity on the moon is
   a. greater than that on earth.
   b. the same as that on the earth.
   c. less than that on earth.

2. The unit for acceleration can be
   a. meters per minute per minute.
   b. meters per minute.
   c. minutes per meter squared.
   d. meters.

3. Compared to a 7 lb. watermelon, a 15 lb. bowling ball falls from the same height
   a. faster than the watermelon.
   b. at about the same speed as the watermelon.
   c. slower than the watermelon.

4. Which of the following has compound motion?
   a. a bowling ball rolling straight down the alley
   b. a baseball that has been hit by the batter
   c. a ping pong ball dropped straight down from the side of a diving board
   d. none of the above

5. In a vacuum, the speed of a freely falling body of three kilograms after three seconds is
   a. greater than
   b. the same as
   c. less than
   the speed of a freely falling body of three kilograms after six seconds.

6. In a vacuum, the acceleration of a freely falling body of three kilograms after three seconds is
   a. greater than
   b. the same as
   c. less than
   the acceleration of a freely falling body of three kilograms after six seconds.

7. An example of terminal velocity is
   a. a feather dropped in a vacuum.
   b. a skater on a frictionless surface.
   c. a baseball caught by a fielder.
   d. raindrops just before they hit the ground.

8. At terminal velocity,
   a. the downward force is greater than the upward force.
   b. the upward force is greater than the downward force.
   c. the upward force equals the downward force.

9. Any mass
   a. has inertia.
   b. has the property of gravity.
   c. has volume.
   d. all of the above are true

10. An important distinction between mass and weight is that
   a. an object may have weight but not mass.
   b. weight is a force and mass is not.
   c. mass is always smaller than weight.
   d. the weight of an object is always the same.

11. A unit for weight could be
   a. kilogram.
   b. $kg \cdot m/s$.
   c. cm/s^2.
   d. newton.

12. Gravity is
    a. a force.
    b. a property of mass.
    c. intangible.
    d. all of the above

13. As astronauts get further away from the earth, their masses
    a. increase.
    b. decrease.
    c. stay the same.

14. When an object falls freely in a vacuum,
    a. the velocity cannot become greater than 9.8 cm/s.
    b. the speed decreases until the terminal velocity is reached.
    c. the speed increases until the terminal velocity is reached.
    d. the speed constantly increases.
    e. the acceleration is zero.

15. Weight and distance from the earth are related
    a. directly.
    b. inversely.
    c. there is no relationship.

16. An object falling at the surface of the Earth without friction will reach a speed of 39.2 m/s in
    a. 1 s; b. 2 s; c. 3 s; d. 4 s; e. 5 s.

The following questions require short answers.

17. A tennis ball machine punches a ball straight out at the same time that one is dropped downward from the same height. Which hits the ground first?

18. A piece of paper and a metal washer the same size and shape are dropped off the edge of a cliff on the moon. Which hits the ground first?

19. Why wouldn't a person reach terminal velocity who was falling toward the surface of the moon in a parachute?

*20. Select the best choice for the following statement.
The minimum speed required to escape from the Earth's gravitational attraction is called
    a. orbiting velocity.
    b. escape velocity.
    c. terminal velocity.
    d. final velocity.

*21. A satellite is launched from the Earth at a speed of 19 000 miles per hour. Does it go into orbit?

*22. What is the difference between being weightless in free fall and being weightless in outer space?

*23. Why does the Moon orbit the Earth instead of falling onto it?

15

WORK AND MACHINES

DAVID, TOM, AND THE LIFTING CONTEST

David challenged mighty Tom, the blacksmith, to a lifting contest. Tom laughed and laughed. "You puny runt," Tom roared, "how dare you challenge me? I can lift tons. I can lift ten barrels." David looked coolly at him. "Just lift one barrel," David said, "which I shall fill. Lift it up two feet to the top of this platform." While Tom sneered, David filled the barrel with iron horseshoes, hammer heads, and small but heavy anvils. The entire town gathered around to watch.

Tom bent down and tilted the barrel over so that it lay on its side. Then, he grabbed the barrel at both ends, bent his knees, and heaved and strained to lift it. He grew red in the face. The barrel stayed where it was. He let go and tried it again but couldn't lift it up. "I'll have to use a pulley," he said. "Go right ahead," responded David.

Tom went to the top of the platform and mounted a pulley on it. He led a rope over the top of the pulley and attached the bottom end to a rope around the barrel. Then, he mounted the platform, seized the other end of the rope in his hands, and pulled the rope downward with all his strength. The barrel didn't move upward at all.

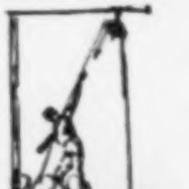
"You'll have to take out some of the weights in it," said he to David. "Neither one of us can lift it."

"No," replied David. "Just watch and see." David took two long boards and propped them up side by side so that the upper end of each rested on the top edge of the platform. Then, he made no effort to lift the barrel, but just rolled it to the bottom end of the planks. Slowly, slowly, he rolled the barrel up the ramp of boards to the top of the platform. The townspeople cheered.

"That's not fair," yelled Tom. "You used a machine."

"So did you," responded David. "Your pulley was a machine but all it tried to do was to change the direction of your force. My machine made it possible to reduce the force I had to use. I did the same work that you tried to do but I did it using less force."

Tom watched dejectedly as David was carried off on the shoulders of his friends to celebrate.



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•Activity 15.1 THREE SIMPLE MACHINES, Part I

Purpose: to discover the principle governing simple machines

Definitions:

Inclined plane: Inclined means tilted; a plane is a flat surface. *An INCLINED PLANE is a tilted flat surface such as a ramp or an uphill road.*

Lever: *A LEVER is a stick or board with a fulcrum. A FULCRUM is an edge which fits under the board or stick and allows it to pivot.*

Pulley: *A PULLEY is a wheel which is turned by a rope or chain that fits into a groove around its rim. A FIXED PULLEY can rotate but can't be moved up or down from its location.*

Stations:

Station 1, The Inclined Plane: board (about 1 m long) leaning against a table top or desk top, metal toy car, spring scale

Station 2, The Lever: a seesaw device with fulcrum off center and weight on one end; weight can be lifted without shifting the weight itself by pressing down on various points on the other side.

Station 3, The Pulley: movable pulley attached to stand, weight

Discussion:

If you have not yet read "David, Tom, and the Lifting Contest," do it now.....Both David and Tom tried to carry out the same task, to lift a weight upward a certain height. Both used a machine but Tom's machine only changed the direction of the force. David's machine did something else; it reduced the force needed to accomplish the task. How does the machine do this? It is your task today to find out. Mother Nature never gives something for nothing. If she allows you to reduce the force, something else must have changed. Hint: in this case, something else must have increased. What is it?

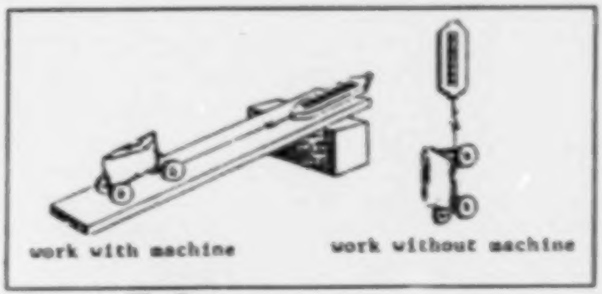

Figure 1. The Ramp

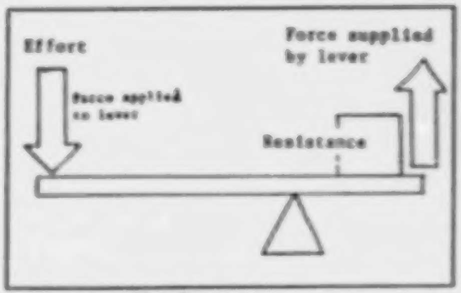

Figure 2. The Lever

Procedure: THE INCLINED PLANE, LEVER, AND PULLEY

1. Go to Stations 1, 2, and 3 and use the machines. Each of these machines accomplishes the same kind of thing as Tom's machine did. Each, in a different way, lifts a weight a certain height. When you have found the secret as to which variable is increased for each of the three machines, return to your seat.
2. Participate in a class discussion on the principle governing these machines.

Questions

Q. 1 Each machine accomplished the same type of task. What was it?

Q. 2 What supplied the force needed to operate each machine?

Q. 3 How did the effort force you supplied compare to the force needed without the machine?

Q. 4 What else changed besides the effort force?

Q. 5 How did Mother Nature compensate (what principle governed) when the lever was used to decrease the effort force?

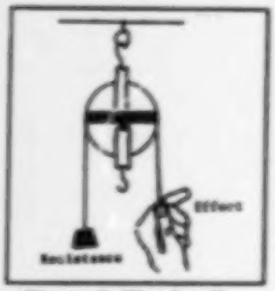

Figure 3. Fixed pulley

Q. 6 Tom used a pulley but his was different from yours. Tom's pulley wheel couldn't move up or down; it was a fixed pulley. At the left is a drawing of a fixed pulley. Based on what you learned in this activity, why didn't Tom's pulley change the force needed?

Q. 7 A machine can be used to change the *force applied by the user (EFFORT FORCE)* to lift an object. What else does it change?

Q. 8 Some machines can be used without changing the effort force needed. What do such machines accomplish?

Q. 9 What are the two variables in this activity and what kind of a relationship exists between them?

Conclusion: State the principle governing the use of machines which change the effort force.

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*Activity 15.2 THREE SIMPLE MACHINES, Part II

Purpose: to continue the study of the principle governing the simple machine

Materials: nonflexible ruler, pencil, and a book

Discussion: One of the machines studied in Activity 15.1, the lever, can also be used to increase the force needed to lift the weight (rather than to decrease it).

Procedure:

1. At your desk, work with a nonflexible ruler and a pencil. Use the ruler as the lever board, the pencil as a fulcrum under it, and the book as a weight. Find out how to increase the force you have to exert. To do this, start with the fulcrum near one end of the ruler and use the lever to lift the book. Then, move it one or two centimeters toward the other end and again lift the book. Move it closer to the other end several times until you have accomplished your purpose.

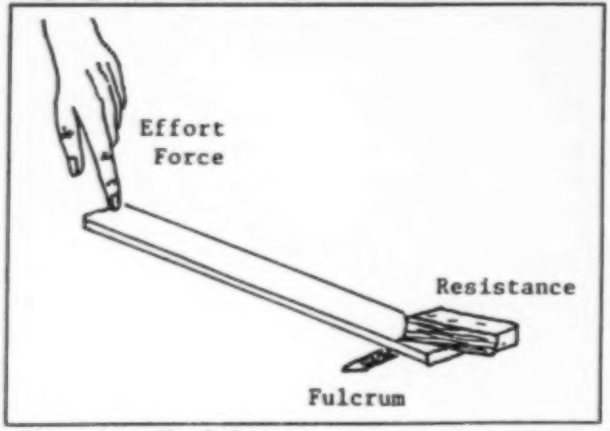


Figure 4. A Simple Lever

2. It is not easy to observe changes in the effort distance for this activity (the vertical distance that the book is lifted). You can, instead, substitute the distance from the force (your finger) to the fulcrum. (You can substitute it because the distances to the fulcrum are proportional to the distance the forces

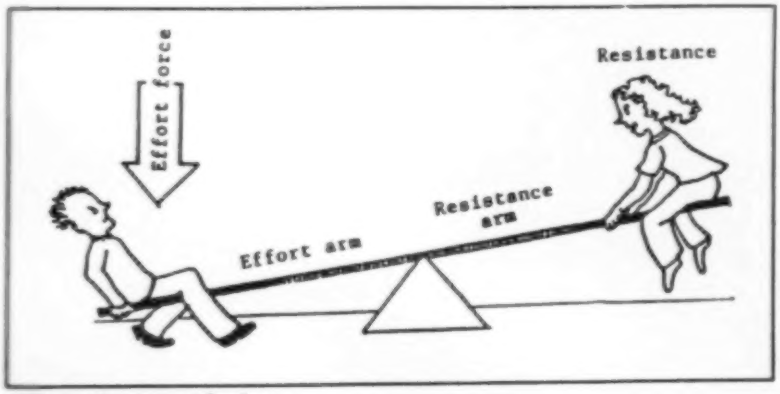


Figure 5. Arms of a Lever

move.) What happens to the distance from the force to the fulcrum, called the effort arm length, as you increase the force needed by moving the fulcrum?

Questions:

Q. 1 How did Mother Nature compensate (what principle governed) when the lever was used to increase the effort force?

Q. 2 The lever may be used to increase or decrease the effort force.
  a. **What did you do to make the lever increase the effort force?**
  b. **What did you do to make the lever decrease the effort force?**

Q. 3 What is the relationship between effort force and effort distance when the effort distance is increased?

Q. 4 What is the relationship between effort force and effort distance when the effort distance is decreased?

Q. 5 What is the relationship between effort force and effort distance for the three simple machines you have studied so far?

Conclusion: Write your conclusion in your report.

*Activity 15.3 WHEEL AND AXLE, SCREW, WEDGE

Purpose: to apply the principle of the machine to understanding the wheel and axle, the screw, and the wedge

Materials:

Station 1, The Wheel and Axle: rotary pencil sharpener, knife
Station 2, The Screw: block of wood with screw in part way, nail partly driven into wood
Station 3; The Wedge: block of wood with wedge hammered part way into it, razor-like knife partly driven into wood

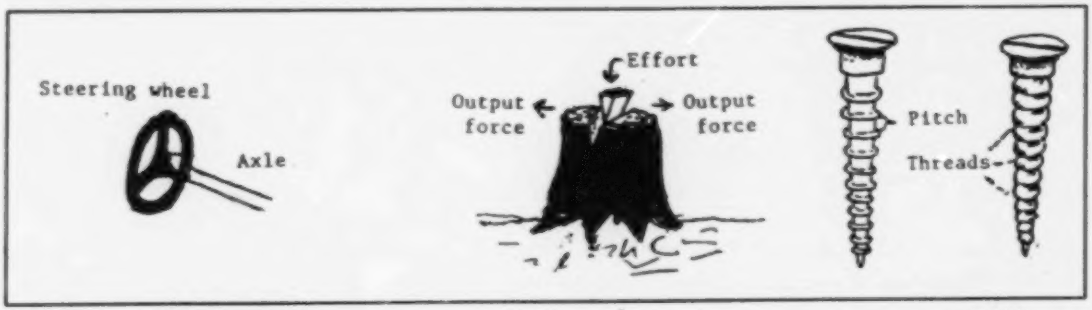


Figure 6. Wheel and axle wedge screw

Discussion: These three machines operate upon the same principle as in Activities 15.1 and 15.2. They differ in that they do a different task. Each station shows an example of a machine and of a tool needed to do the same job without the machine.

The wheel and axle (an *AXLE* is a *shaft or pole* through the center of a wheel) are used to move the blade in the pencil sharpener. It can be compared to a knife that is moved around the pencil to shave it.

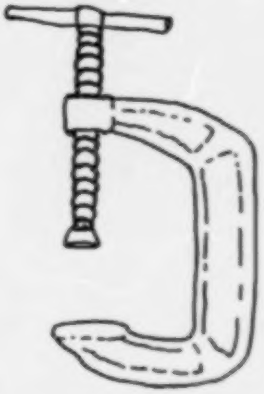
The threads in the screw change the motion from straight downward into the wood into a rotary motion. The screw is the machine; a nail does the work without the machine.

The wedge forces aside the two sides of the block as it moves down. It can be compared to an ultra-thin knife driven into the wood to split it.

The way that these machines obey the law of the machines is less obvious, perhaps, than in Activities 15.1-2.

Procedure: Examine the machines or the drawings of them. Work with your team or partner to understand how these machines act. For your Report Sheet, you can turn in a set of drawings with captions or you can turn in a discussion which explains how each machine obeys the law of the machine.

Questions



Q. 1 When a bucket of water is lifted from a well by turning a handle,
  a. where is the axle?
  b. is more force needed with the wheel and axle than without it?

Q. 2 Name the type of machine for each of the following.
  a. axe; b. C-clamp; c. door stop

Q. 3 a. Which is greater, the distance around that the screw is turned by the screwdriver or the distance that it moves into the wood?
  b. Which is greater, the force needed to turn a screw or the force that the screw exerts against the wood?
  c. What is the relationship between distance and force for a wood screw?

Q. 4 What part of the screw controls how far into the wood it goes for a certain effort distance?

Q. 5 When you pedal a bicycle,
  a. which is longer, the distance around the circle that your foot goes or the distance around that a point on the rim of the wheel goes?
  b. Is the effort force pedaling a bicycle greater than turning the wheel without the pedal?

Section 15 . 1 THE MACHINE WORLD

Imagine if all the simple machines in the world suddenly stopped functioning! All the electric machines, the fuel-powered ones, and all those powered by human labor would stop because they are all based on the simple machines. Machines make our mighty civilization possible.

A simple machine is used (1) to change the direction of a force,
and/or (2) to change the size of a force.
A combination of simple machines is called a COMPOUND MACHINE.

Exercise 15.1

15-1 a. What can a simple machine accomplish?
  b. What can a compound machine accomplish?

15-2 List the six simple machines.

Section 15 . 2 WORK DONE BY A MACHINE

15.2 A RELATIONSHIP BETWEEN FORCE AND DISTANCE

Activities 15.1 - 15.3 examined the six simple machines. For each, there was work which could be done either without the machine or with the aid of the machine. In every case, the machine allowed a different force to be used than when doing the same task without the machine. When the force became smaller, the distance through which the force had to be exerted became longer. Conversely, when the force that had to be exerted by the machine operator increased, the force was exerted through a smaller distance. By changing the distance, the force is changed.

For any given task using a simple machine, the relationship between force and distance is **INVERSE.**

If force decreases, the distance increases. F ↓ d ↑

If force increases, the distance decreases. F ↑ d ↓

This is the governing principle of all the simple machines.

Exercise 15.2 A

15-3 Does the effort force each time the machine is used increase or decrease when

a. Jill moves to the very edge of the seesaw to lift Jack while Jack moves closer to the pivot?

b. the ramp to the loading platform is replaced by one that is shorter (and therefore steeper?

c. the effort distance of a machine increases?

d. the number of threads per centimeter on a screw increases?

e. the rotary handle on a sharpener is lengthened?

15.2 B WORK

Can the relationship between force and distance using a machine be expressed quantitatively? Scientists have found a fundamental connection between force and distance for a given task which can be expressed exactly. The product of the force and the distance through which it operates is always the same as long as the task remains the same. It can be expressed mathematically as follows:

force x distance = constant

To see why a constant product is always an inverse relationship, consider the example of the pairs of numbers that can be multiplied to make 24. The 24 acts as the constant.

First factor	X	Second factor	=	Product	First Factor	Second factor	Product
24	x	1	=	24			
12	x	2	=	24	decreases	increases	constant
8	x	3	=	24	decreases	increases	constant
6	x	4	=	24	decreases	increases	constant

When the first factor becomes smaller (24, 12, 8, 6), the second factor becomes bigger (1, 2, 3, 4). That's because the product always equals the constant, 24. If the first factor started to increase, the second would decrease correspondingly to keep the product at 24. Therefore, whenever the product of quantities of two variables equals a constant, the two variables are inversely related.

The special name, WORK, is given to any product of force and distance, whether or not their product equals a constant and whether or not a machine is used. We will consider the other cases in a later section. For now, consider the special case where the work is constant. The symbolic equation for the quantitative relationship may be written as

W = Fd where W = work, F = force, d = distance

Exercise 15.2 B

15-4 Given a constant product equal to 18 for two variables, (units are omitted), show how the two variables are related.

15-5 Given that y = 5 smoots and x = 13 shmerks, and that yx is constant,

a. write an equation to show the relationship.

b. what happens to y if x becomes smaller?

c. what is the relationship between y and x?

15-6 Given the equation, F = ma, what is the relationship between

a. F and m; b. F and a; c. m and a

Activity 15.4 THE INCLINED PLANE

Purpose: to observe the relationship between force and distance for the same work using an inclined plane

Materials: a toy car with ball-bearing wheels or a roller skate, smooth board long enough to lean on your desk or top of your chair, spring balance with hook, string about 0.5 m long, meter stick

Procedure:

Step 1: NO MACHINE

1. Obtain the car and spring balance.
2. Use the spring balance to weigh the car in newtons. This is the force needed to lift the car without the aid of the machine.
3. With the car hanging on the spring, slowly lift it up and down to see how the weight of the car changes.
4. Record the weight of the car.

Step 2: RAMP ONE

1. Obtain the board and meter stick.
2. Lean the board against your desk (or chair) so that the top end of the board extends at least 30 cm past the top end of the desk or chair. This is Ramp One.
3. Hook the spring balance to one end of the car. Starting from the bottom, pull the car slowly up the board at a constant speed. Record the force reading. Set the car and balance down.
4. Measure and record the length of the board from the bottom to where it first touches the back of the chair of the desk.
5. Measure and record the height of the desk (the distance to which the car is lifted without the ramp).

Step 3: RAMP TWO

1. Place the car on the board as if it had been pulled to the very top of the board. Reset the board at an angle so that the back wheel of the car is at the height of the desk. This is Ramp Two. Set the car down.
2. Obtain and record the force reading for pulling the car up Ramp Two.
3. What is the length of Ramp Two?
4. Is Ramp Two longer or shorter than Ramp One?

Step 4: CALCULATIONS

Carry out calculations on your Report Sheet to find out whether the work done in this activity was equal to a constant. (Use the equation, $W = Fd$.) Explain.

Conclusion: Write your conclusion in your Report Sheet.

Section 15.3 EFFICIENCY

Work can be done more easily with than without a machine. In some cases, as with an inclined plane, the force can be reduced. In other cases, as with a fixed pulley, the direction of the work can be changed without changing the force. In still other cases, as with a bicycle the force needed is stronger than without the machine because it has to be applied over a shorter distance.

In every case, the work done without the use of the machine can be calculated. This is the same work that the machine can deliver. That is, with or without the machine, the same work has to be done.

The work that the machine can deliver is called the OUTPUT WORK.

For an inclined plane, the output of the simple machine is to lift an object up to a height. We can calculate the output work by multiplying the vertical height to which the object is lifted by the force required to lift the object straight up (its weight).

In every case, the machine provides an output which, like the effort, is a product of a force multiplied by the distance.

If there were no friction, we would expect the effort work to exactly equal the work produced by the machine, the output work. Alas, no machine is frictionless. Every machine has moving parts; moving parts develop friction. For example, you have to move the object up an inclined plane.

IDEAL MACHINES are frictionless; all real ones have friction in them. Ideal machines do not exist. When friction is present, it acts as a force operating through the same distance but in the opposite direction to the motion. As a result, friction does work which opposes the effort work. Some of the work put into the machine must be used just to overcome friction. Hence, in the real world, the effort work (the work imput) is ALWAYS greater than the output work (actual work done by machine).

The actual work done always equals the ideal work PLUS the frictional work.

The EFFICIENCY of a machine compares the ideal to the actual work, that is, it compares the work output to the work imput. The greater the input work that has to be done, the less the efficiency.

$$\frac{\text{Ideal work}}{\text{Actual work}} \times 100\% = \text{Efficiency} \quad \text{or} \quad \frac{\text{Work output}}{\text{Work imput}} \times 100\% = \text{Efficiency}$$

From the above equation, you can see that if the actual work equals the ideal work, then

$$\frac{\text{Ideal work}}{\text{Actual work}} = 1 \quad \text{and the efficiency of the machine} = 1 \times 100\% = 100\%$$

so the efficiency of an ideal machine is 100%. Since the efficiency of the real machine is always less than that of the ideal machine, it is always less than 100%. The closer the efficiency is to 100%, the more efficient the machine is.

Ideal machine: efficiency = 100% *Real machine: efficiency less than 100%*

The more moving parts in a real machine, the less efficient it is. An automobile is a machine made up of many simple machines with an efficiency of about 24%.

Since there is some friction in any machine, there is no such thing as a perpetual motion machine. A perpetual motion machine would be an ideal machine, and it would run forever once it was started. In every real machine, extra effort work must always be added to make up for effort work wasted by friction.

Exercise 15.3

15-7 On a school test, William calculated that a machine had an efficiency of 105%. Without looking any further, the teacher marked it wrong. Why?

15-8 Aliasha applies 600 units of work to a machine. The machine produces 550 units of work to move some objects.

a. Is this an ideal machine? Explain.
b. What is preventing this from being an ideal machine?
c. What is the efficiency of this machine?

15-9 Edison Watt has applied for a patent for a machine. After it has started, it can turn a wheel round and round without stopping and without any additional fuel. Watt will not get the patent. Why?

Section 15.4 MECHANICAL ADVANTAGE

15.4 A Meaning

The mechanical advantage tells us how good a machine is at reducing the needed force compared to doing the work without the machine. *The MECHANICAL ADVANTAGE (abbreviated as MA) is the ratio of the force delivered by the machine compared to the effort force.* The MA has no units since they cancel out, as with all ratios. The smaller the effort force needed, the greater is the mechanical advantage that the machine provides.

For example, if a machine reduces the force needed to one-half of that without the machine, we say that it has a mechanical advantage of 2.

If a machine has a mechanical advantage of five, the force produced by the machine is five times as much as the effort force put into it. To put it another way, the effort force is only one-fifth as great as the resistance force when MA = 5.

The smaller the effort force needed, the greater is the mechanical advantage of the machine. For the following, the resistance force is the force needed to do the work without the machine.

Resistance force = effort force	MA = 1
Resistance force greater than effort force	MA greater than 1
Resistance force less than effort force	MA less than 1

Exercise 15.4A

15-10 For each of the following, compare the effort force to the resistance force.
a. MA = 4; b. MA = 1; c. MA = ¼ .

15-11 Is the MA of a ramp greater than, less than, or equal to one?

15-12 A small ferris wheel is operated manually by turning it with a handle at its hub. Hence, it is being operated as a wheel and axle machine. Compared to just rotating the rim of the wheel manually, is its mechanical advantage greater, equal to, or less than one?

15-13 A seesaw has a mechanical advantage of two. Is the fulcrum in the middle?

15-14 Comparing a dressmaker's scissors to pruning shears (the latter has long handles), which has the greater MA?

15-15 Which has a greater MA, a wedge or a knife? Why?

15-16 Which has a greater MA, a long ramp or a short one with the same vertical height?

15-17 Which has a greater MA, a wood screw with many threads or one the same length with less threads?

Optional: 15.4 B CALCULATION OF THE MECHANICAL ADVANTAGE

For most machines, it is easier to measure the distances involved rather than the forces used. Since there is an exact inverse relationship between force and distance for a machine, it is possible to calculate the mechanical advantage using distances instead. To make the calculation, the effort distance appears in the numerator of the ratio and the distance used without the machine (output or resistance distance) in the denominator.

For an inclined plane, $$\text{MA} = \frac{\text{length of ramp}}{\text{vertical height to which object is lifted (without machine)}}$$

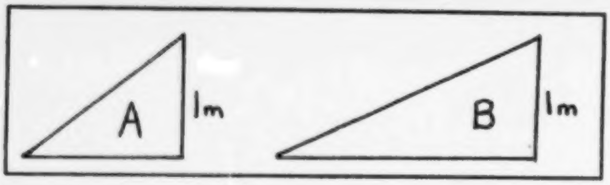
For a lever, instead of using the distances through which the force moves, it is easier to use the distances from each force to the fulcrum (see Fig. 5, effort arm and resistance arm); since these are proportional to the actual distances, their ratio can be used.

The mechanical advantage of a lever is usually calculated as $\dfrac{\text{effort arm}}{\text{resistance arm}}$.

Exercise 15.4B

15-18 For each of the following, compare the length of the effort arm to the resistance arm.
a. MA = 4; b. MA = 1; c. MA = 1/4

(Exercise 15.4 B is continued on the next page)

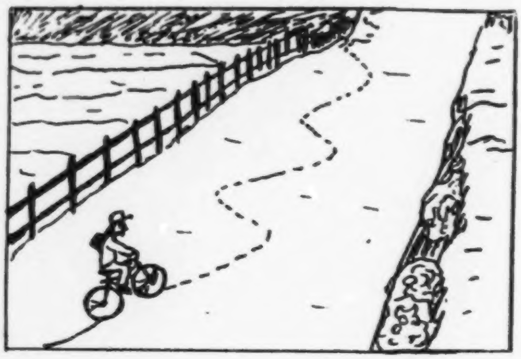


15-19 The length of ramp A to reach a platform one meter high is 4 m. Ramp B to the same platform is 6 m long.

a. Which ramp needs the smaller effort force?

b. Which ramp has the larger mechanical advantage?

c. What is the mechanical advantage of each ramp?



15-20 Why is it easier for a cyclist to zigzag from side to side in order to go up a hill rather than to go right up it?

15-21 Helen is sitting on one side of a seesaw whose fulcrum is in the middle; Maria is on the other side. The seesaw is balanced when Helen is sitting 2 m from the fulcrum while Maria is sitting 1.5 m from it on the other side.

a. What is the mechanical advantage of this machine?

b. Who is heavier, Helen or Maria? Explain.

15-22 With respect to distance, when is the mechanical advantage greater than one for a lever?

15-23 A windlass on a well is operated so that the effort distance is 200 cm when the bucket is lifted 1 m. What is the MA for this machine?

Optional: Section 15.5 THREE CLASSES OF LEVERS

There are three classes of levers depending on the order of arrangement of the fulcrum, effort force, and resistance (weight to be moved). For all three classes of levers, the further the effort force is from the fulcrum, the smaller the effort force needs to be. To help you remember the three classes which are shown below, use the acronym FREE as shown in the following.

Class	Between the other two	Examples
First	**F**ulcrum	shovel, scissors, crowbar
Second	**R**esistance	wheelbarrow
Third	**E**ffort force	baseball bat, broom, hoe, fishing line
and	**E**asy to do	

Unlike the other two, the third class lever is different in that it always has a mechanical advantage of less than one. With the effort force above the fulcrum at one end, as in a baseball bat, the user has to exert a strong force to cause the other end to sweep out a longer distance. For example, when you hold the upper end of a broom, the fulcrum is just above your hands. The resistance is at the bottom. As you move the upper end of the broom a short distance, the bottom end sweeps out a longer distance.

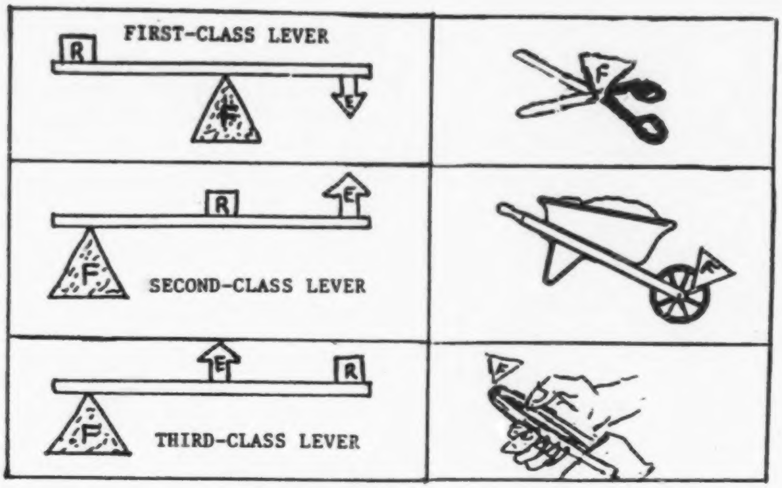


Figure 7 Three Types of Levers

Exercise 15.5

15-24 Draw a picture of a baseball bat and, with labeled arrows, show the fulcrum, effort force, and resistance.

15-25 Draw a picture of a wheelbarrow and, with labeled arrows, show the effort force, fulcrum, and resistance.

15-26 Why is it desirable for a broom to have a mechanical advantage of less than one?

Optional: Section 15.6 THE PULLEY

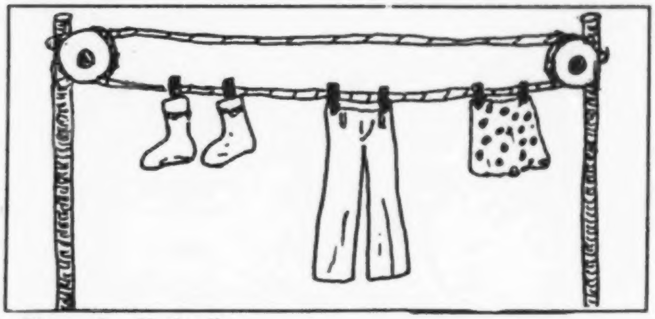


Figure 8. Clothesline

**Q. 1 In the diagram of the pulley shown left, when the upper part of the rope is pulled to the right, what happens to the direction in which the socks move?

**Q. 2 Is the clothesline a fixed or a movable pulley?

**Q. 3 What is the mechanical advantage of a clothesline?

A movable pulley can be moved up or down as the rope is tugged. It reduces the force and can also change its direction. The effort force is the pull on the free end of the rope. The effort distance is the distance that the free end moves. Using a movable pulley, for example, you might pull the rope one meter down to lift the object one-half meter upward. Thus, you would reduce the force needed by one-half.

The greater the number of supporting ropes for movable pulleys (a supporting rope is an upward pulling rope; see Figure 9), the less the force needed to do the task. The mechanical advantage of a pulley is equal to the number of supporting ropes.

Combinations of pulleys can greatly decrease the force needed. A heavy machine that cannot be lifted by a person alone can be lifted with the aid of a combination of pulleys called a block and tackle.

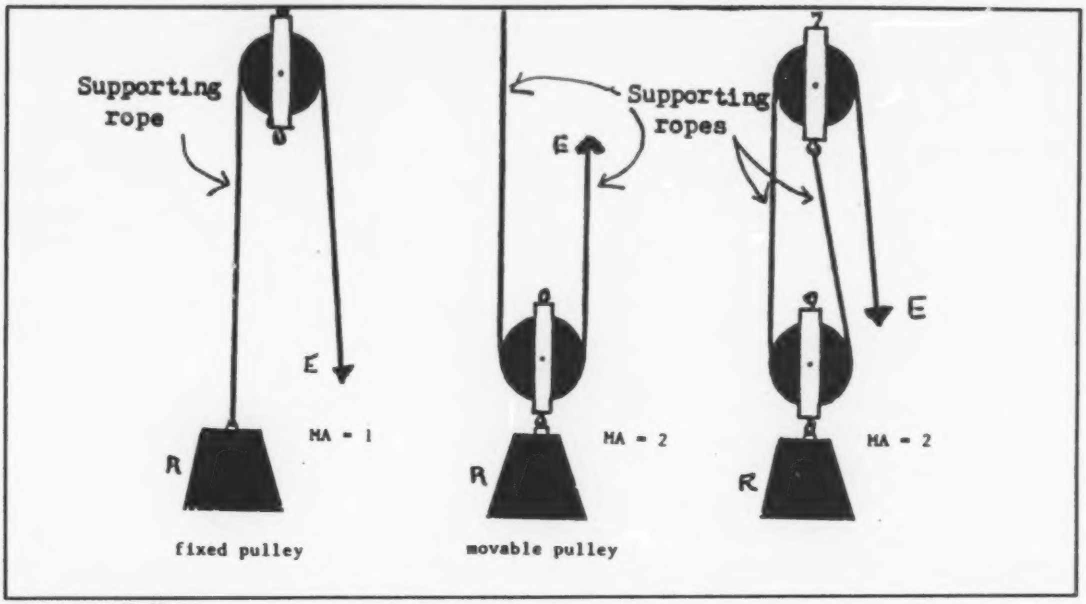


Figure 9 Pulleys

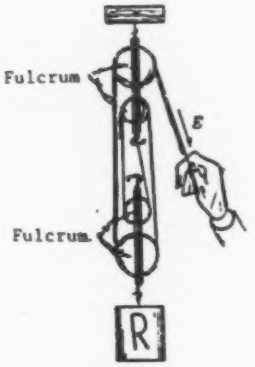
Exercise 15.6

15-27 When the rope of a fixed pulley is pulled downward, what is the direction of the force exerted by the pulley?

15-28 Which requires less effort force, a pulley with four supporting ropes or one with three?

15-29 Does a movable pulley always give a mechanical advantage greater than one?

15-30 a. How many supporting ropes are there in the block and tackle shown in the diagram at the right?
b. What is the MA for this block and tackle based on the number of supporting ropes?



Block and Tackle

Answers to Q's

Q. 1 The socks move to the left.

Q. 2 The clothesline is a fixed pulley.

Q. 3 MA = 1.

Section 15 . 7 WORK

Work in science has a very exact and different meaning from our ordinary form of work. We have already seen it applied to the special case of the machine. In its general form, $W = Fd$, any or all of the symbols may stand for a variable; the product need not be constant. Work is done whenever a force pushes or pulls an object through a distance.

You already know how to look at an equation and decide what proportional relationships and what inverse relationships it shows.

If the equation can be rearranged so that any pair of variables form a Per Fraction, those two variables are proportional to each other.

If it can be written so that two variables are multiplied by each other, those two variables are inversely related.

**Q. 1 Which variables are directly proportional to each other in the work equation?
**Q. 2 Which variables are inversely related in the work equation?

Following are two examples of the proportional relationships in the work equation.

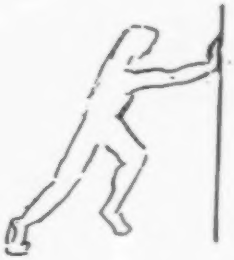
Example 1: (The work is proportional to the distance when the force is constant.)
If you push a supermarket cart for any distance, you are doing work equal to the force exerted multiplied by the distance. If you push it for a longer distance (distance increases) with the same force (force is constant), you do more work (work increases).

Example 2: (Work and force are proportional when distance is constant.)
When you kick a soccer ball, you do work because you apply a force for the distance when the ball is in contact with your foot. If you increase the force (force becomes bigger) for the same distance (distance is constant), you do more work (W becomes bigger).

Work can be defined directly from the equation. **Work is done whenever a force operates through a distance.** The force must operate through a distance; no distance, no work.

**Q. 3 You may feel that you are working very hard when you are sitting and thinking about homework but, scientifically, you are not working at all. Why?

Similarly, no work is done by pushing at a brick wall; the wall pushes back to balance the forces and so the forces do not operate through a distance. In order for work to be done, the brick wall would have to crash so that the force moves along a distance. For the same reason, a book on a desk does no work.



Exercise 15.7

15-31 In which of the following is work done?
- a. A cart is pushed up a hill.
- b. A boy is standing.
- c. A spaceship moves through frictionless space at constant speed.
- d. A tray is lifted.
- e. An object falls down.

15-32 Based on the equation W = Fd,
- a. if the force exerted to push a cart increases, is more or less work done for the same distance?
- b. if a cart is pushed with the same force for 2 km instead of 1 km, does the work done increase or decrease?
- c. if the same work is done on a cart for 5 m as for 10 m, does the force remain the same? If not, how does it change??

15-33 Given the speed equation, $v = d/t$, it is rearranged to $d = vt$.
- a. From the equation, when distance is constant, what must happen to the time needed if the speed is increased?
- b. From the equation, what happens to the speed if the time takes longer for the same distance?
- c. From the equation, what happens to the time if the distance is doubled going at the same speed?

Answers to Q's
Q. 1 Work and force are directly proportional. Work and distance are directly proportional.
Q. 2 Force and distance are inversely related.
Q. 3 No distance, no work.

Activity 15.5 IDENTIFYING SIMPLE MACHINES

Purpose: to identify simple machines and how they work

Procedure: You will find Stations around the room at each of which a different machine is placed.

For some of the machines, you will be given a drawing. Your task for each is to identify it as one of the six simple machines and to identify the location of the effort force and effort distance. Then, show where the force and the distance developed by the machine wheel are located. If the machine has a fulcrum, identify its location, too. You may have to draw some of the machines yourself.

Section 15.8 MEASUREMENT OF WORK

15.8 A UNITS

Since work = force x distance, its measurement units are those for force multiplied by those for distance. Thus, work can be measured in newton · meters. Scientists have shortened this unit by naming it the joule.* *One JOULE equals one newton-meter.* (JOOL). The joule is the SI unit for work.

$$F \cdot d = W$$

$$1 \text{ newton} \times 1 \text{ meter} = 1 \text{ newton-meter} = 1 \text{ joule}$$

$$1\ \text{N} \times 1\ \text{m} = 1\ \text{N} \cdot \text{m} = 1\ \text{J}$$

Hence, whenever force is measured in newtons and distance in meters, the work done is in joules.

Exercise 15.8 A

15-34 What is meant by a joule?

Optional: 15.8 B CALCULATIONS USING THE WORK EQUATION

If force and distance are known, the quantity of work can be calculated from the equation for work.

Example 15.1

Problem: An object weighing 175 N is lifted to a height of 4 m. How much work is done?

Solution

Step 1: W = ___ J

Step 2: 175 N, 4 m

Step 3: The upward force exerted to lift the object is equal and opposite in direction to the weight of the object.

$W = F \cdot d = 175\ \text{N} \times 4\ \text{m}$ Units check since $\text{N} \cdot \text{m} = \text{J}$

Step 4: $= 700\ \text{N} \cdot \text{m} = 700\ \text{J}$

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[*] The joule is named after a famous investigator of scientific work called James Prescott Joule (1819-1889).

Exercise 15.8B

15-35 A force of five newtons is exerted through a distance of one-half meter. How much work is done?

15-36 A object weighing 25 N is lifted to a platform 1.5 m high. How, much work is done?

15-37 Given that a force of 10 N is operated for a distance of 30 cm, how much work is done measured in SI units?

Section 15.9 POWER

The time is far in the future. The place is a planet on a distant star once colonized by Earth but long since reduced to savagery. The only remnants of that time are two identical powerful pile drivers which still operate and which stand sixty meters high and about one kilometer apart. Each press is worshipped by a different primitive tribe. The Oogs sacrifice to a press which takes one week to descend, then quickly rises up again until it reaches the top and then descends again. Depending on the time of the year, they sacrifice different animals by placing one under the giant hammer. The Bogs sacrifice to their press which takes two weeks to descend. However, they sacrifice human captives! As a result, the Oogs have declared war on the Bogs. The Oogs are sure they will win because they believe their god is more powerful than the Bog god. Is their god, indeed, more powerful?

The Oogs' giant press is indeed more powerful, at least scientifically. It does exactly the same work as that of the Bogs' press but the Oogs' press does it faster. Scientifically, ***POWER is work done per unit of time.***

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{\text{force x distance}}{\text{time}} \quad \text{or} \quad P = \frac{W}{t} = \frac{Fd}{t}$$

Watts, kilowatts, and horsepower are units of power. The ***WATT**, W, equals one joule per second*; it is the SI-metric unit of power.

$$\text{Power (in } \frac{\text{joules}}{\text{second}}) = \frac{\text{work (in joules)}}{\text{time (in seconds)}}$$

The kilowatt (kW) equals 1000 watts. One horsepower is about 3/4 kW.

Exercise 15.9

15-38 Which has a higher power rating, a printing press that uses 5 joules/hour or a rotary drill that uses ½ J/s?

15-39 Which has a higher power rating, the Oog's pile driver or the Bog's pile driver? Explain.

15-40 Arrange in the order of size beginning with the biggest unit; one watt, one kilowatt, one horsepower.

15-41 If 1 kilowatt is 1000 J/s, what is a kilowatt-second (remember that the dash in kilowatt-second is the same as a multiplication sign)?

15-42 How many joules equal a kilowatt · hour? Electric bills charge for kilowatt-hours of electricity used. (Hint: convert hours to seconds.) The electric company charges consumers for the use of their electricity in kilowatt-hours; you can see this if you look at the electric bill for your home.

Activity 15.6 THE RUBE GOLDBERG MACHINE

Discussion: A Rube Goldberg machine is a device named after its inventor who featured all sorts of versions of the machine in his comic cartoons. His machines did the most simple tasks in the most silly and complicated ways employing combinations of simple machines. The machines included ramps, stairs, slides, pulleys, and levers to get from the beginning to a target at the end. After the action was started (by dropping a marble, filling a glass on a lever with water, burning a hole through a taut string, or some other unexpected use of force), each step tripped the next one into operation. The target at the end was, perhaps, to tip a piece of candy into a mouth or ring a bell to wake someone up or some other ordinary and simple purpose.

Purpose: to design a Rube Goldberg machine

Materials: Anything in the home easily available may be used. Your teacher will supply steel spheres if needed.

Procedure:

Step 1: Develop the design of the machine. The purpose of each part should be clear. Be sure that the design is capable of operation; you may have to build it.

Step 2: Draw the design. It should be easily readable. Each simple machine in the design must be identified, even when part of a compound machine.

Step 3: Points will be allowed for how well the machine can work, for identification of the simple machines in the design, for the imagination displayed, and for the careful layout of the drawing.

Chapter Fifteen Review

Vocabulary

Fulcrum
Push by a person on a lever
Simple machine
Ideal machine
Mechanical advantage
Compound machine
Real machine
Wedge
Efficiency

From the above list, select the choice which best fills the blanks in the following. Each choice may be used only once.

1. ______________________ : general name for the type of device that changes the direction or size of a force
2. ______________________ : combination of two or more simple machines
3. ______________________ : comparison of work done by real and ideal machine
4. ______________________ : part of a lever
5. ______________________ : effort work is always greater than the work produced
6. ______________________ : no friction present
7. ______________________ : effort force
8. ______________________ : comparison of forces needed
9. ______________________ : knife cutting an apple

Power
Work
Acceleration
Force
Mass
Speed

For each term in Items 10 to 15 below, select the unit from the list above which best matches it.

10. m/s
11. m/s^2
12. kilogram
13. newton-meter
14. joule/second
15. newton

Lever
Wheel and axle
Screw
Wedge
Pulley

Select the type of simple machine for Items 16-20 that best matches it from the choices above. A choice may be used more than once.

16. C-clamp
17. bar used to pry object upwards
18. flag-raising on a pole
19. scissors
20. iron nail

Applications

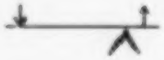
For each of the following, state whether it is true or false.

1. The closer the fulcrum is to the effort force of a lever, the smaller is the effort force.
2. A machine is used to increase or decrease work.
3. For a simple machine, as force decreases, distance decreases.
4. With a movable pulley, the distance the rope moves down is greater than the distance the resistance moves up.
5. All machines decrease the effort force needed to do the work.
6. The more threads on a screw, the bigger the effort distance.
7. A doorstop is a wedge machine.
8. The steering wheel on a car is a wheel and axle mechanism.
9. For a bicycle, the effort force needed to turn the pedal is greater than the force needed to turn the wheel at the rim by hand.
10. A pulley can be used to change the direction of a force.
11. For any ideal inclined plane, a longer one requires more work to be done than does a shorter one going to the same height.
12. The longer the effort distance, the smaller the mechanical advantage.
13. All simple machines which change the force needed to operate the machine do it by changing the distance over which the effort force must operate.

Questions 14 to 29 are multiple choice. Select the best choice.

14. The machine which has a fulcrum is called
    a. wheel and axle.
    b. an inclined plane.
    c. wedge.
    d. a lever.

15. The mechanical advantage of pushing down on this lever is



    a. greater than one; b. equal to one; c. less than one

16. Work is a. Fd; b. ma; c. F/d; d. m/a

17. In which of the following is work NOT done on a box?
    a. lifting the box
    b. pulling the box
    c. holding the box
    d. dropping the box

18. A tractor pulls a load by exerting a force of 1000 N for a distance of 10 m. When the tractor pulls it 30 m instead, the work done by the tractor is
    a. greater than before.
    b. less than before.
    c. unchanged.

19. Given a mechanical advantage of 2, the resistance force is
    a. greater than the effort force.
    b. equal to the effort force.
    c. less than the effort force.

20. Which of the following is not correct? Some real machines
    a. change the direction of a force.
    b. increase force.
    c. have an effort distance equal to the resistance distance.
    d. do a quantity of work equal to the quantity of work done on them.

21. A force of 200 N is exerted through a distance of 2 m using a wheelbarrow. The work done is
    a. 400 N-m
    b. 400 joules
    c. 400 watts
    d. 400 kg · N/m
    e. both a and b are correct

22. If a perpetual motion machine could exist, it would have an efficiency
    a. greater than 100%; b. less than 100%; c. equal to 100%;
    d. Its efficiency cannot be calculated.

23. Compared to the efficiency of an ideal machine, the efficiency of a real machine is always
    a. greater; b. less; c. the same.

24. If a Diesel train moves at a uniform speed, frictional work is being done.
    a. true; b. false

25. Which of the following machines operates with the least friction?
    a. a machine with an efficiency of zero.
    b. a machine with an efficiency of 10%.
    c. a machine with an efficiency of 25%.
    d. a machine with an efficiency of 50%.

26. The mechanical advantage for a ramp is always
    a. greater than one; b. equal to one; c. less than one.

27. A lawn mower is pulled up a long frictionless ramp. The work needed is
    a. less than needed if it were lifted vertically to the same height.
    b. the same needed to lift it vertically to the same height.
    c. greater than that needed to lift it vertically to the same height.

28. Compared to one kilowatt, one horse power is
    a. almost one hundred times as big.
    b. almost one-hundredth of it.
    c. a little smaller.
    d. a little bigger.

The following questions require a short answer and/or calculations.

29. A big stone is lifted straight up out of a hole by a gardener. Another stone the same size is pried up the same vertical distance out of the hole by the gardener with the aid of a long steel bar.
    a. Ideally, which way is more work done?
    b. Does the use of the bar require more or less effort force than without it?
    c. Where is the fulcrum on the bar?

30. A broom has a mechanical advantage of 0.6. Does the broom need a greater effort force than does a brush moved directly along the ground?

31. In rescue operations with ships in dangerously stormy seas, boats cannot be employed to transfer people from a sinking ship to safety. In such cases, a pulley operation like a clothesline is used. Briefly discuss how this works.

32. A heavy bucket of water can be lifted from a well by turning the handle at the side through large circles while the axle turns small circles. Is the mechanical advantage of the bucket system greater than or less than one? Explain.

33. What is the difference between power and work?

34. State whether the relationship is direct or inverse for each of the following:
    a. between force and distance when the same work is done.
    b. between force and acceleration for the same mass.
    c. between distance and time for the same speed.

*35. What is the power rating of an electric bulb that uses 60 J in 4 s?

*36. Jamie is preparing to lift and carry a tray of food on one hand.
    a. Where is the fulcrum on the tray?
    b. What class lever is this?

*37. The tip of a can opener is inserted under the lip of a lid and the opener is pressed down. What class lever is this?

*38. A nutcracker is a second class lever. State where the effort force is and its direction, where the fulcrum is, and where the resistance is.

*39. An electric knife is marked, "100 watts." What is the kilowatt rating of the knife?

*40. A lever is operated so that by exerting a force of 2 N through a distance of 0.5 m, a mass with a weight of 8 N is lifted through a distance of 0.15 m. What was the effort work applied to this machine.?

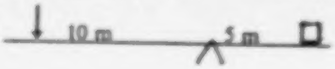
a. 0.5 J; b. 0.6 J; c. 1.0 J; d. 0.08 J; e. 4.0 J.

*41. What is the power rating of a machine that uses 40 J every 5 s for 10 m?

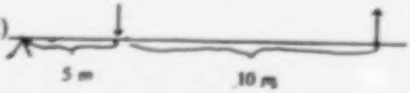
*42. To get to a house 150 m vertically upwards from the entrance to the property, a car must drive around a spiral uphill driveway 350 m long. What is the mechanical advantage of the driveway?

*43. Calculate the mechanical advantage of each of the following levers.

(1)

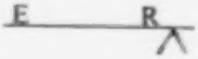


(2)

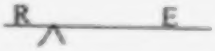


*44. Identify the class of lever for each of the following, where E stands for effort force and R for resistance.

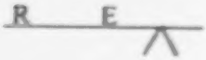
a.

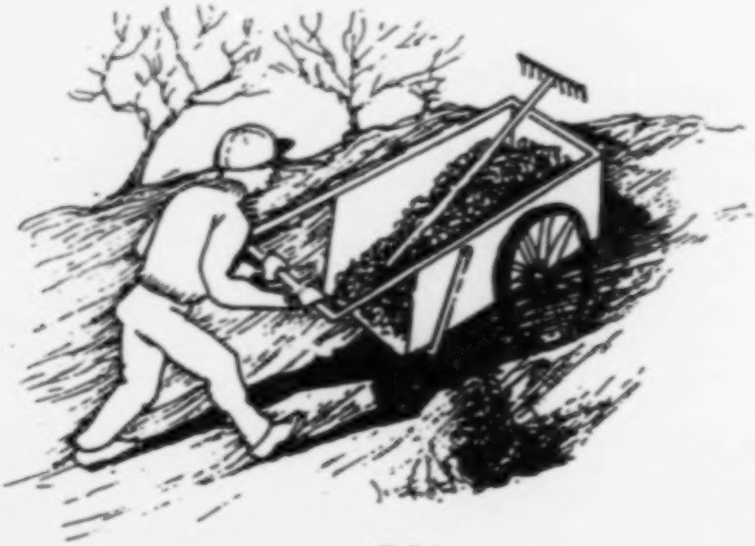


b.

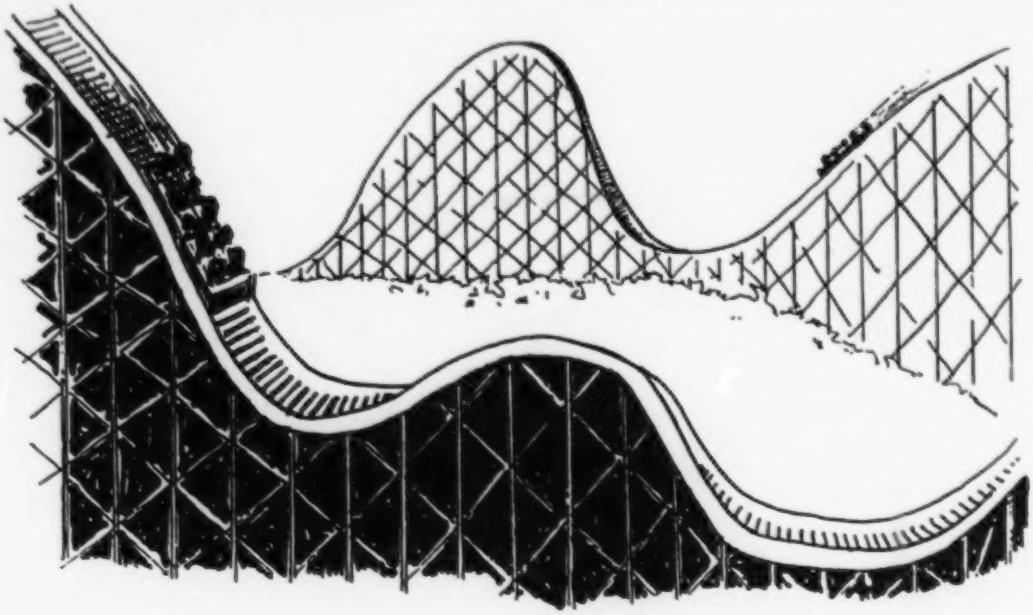


c.





16 ENERGY AND HEAT

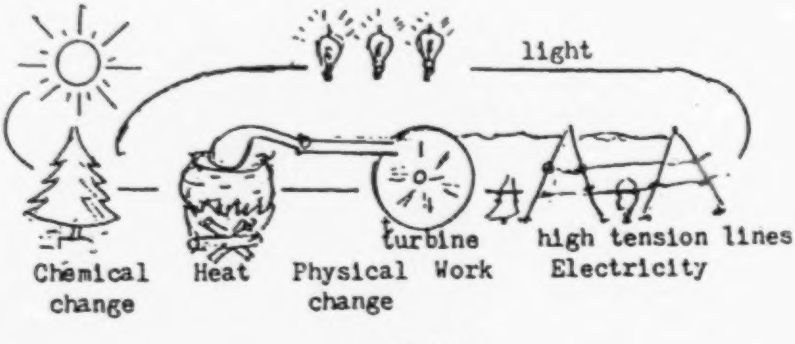


Section 16.1 ENERGY, THE ROOT OF ALL CHANGE

Activity 16.1 FORMS OF ENERGY

When an electric fan is plugged into the wall, electricity is converted into motion. Both electricity and motion are forms of energy. List two devices in your home that use electricity but do not produce motion. Instead, they produce some other output. Each device should produce a different kind of output.

Energy is a fundamental scientific concept which took many, many years to discover. To get an idea of what is meant by energy, consider the following loop, which is explained on the next page. Start with a sunny day.


light
turbine
high tension lines
Chemical change
Heat
Physical change
Work
Electricity

	Process	Change
1.	Sunlight causes tree to grow.	Light → chemical change
2.	Wood is burned to produce heat.	Chemical change → heat
3.	Heat is used to boil water.	Heat → physical change
4.	Steam is used to turn turbine blades.	Gas work → blades work
5.	Turbine is used to produce electricity.	Work → electricity
6.	Electricity lights bulb.	Electricity → light
7.	Light helps tree to grow.	Back to where we started

It looks as if something is being transferred from one part of the sequence to the next and on and on, something intangible. Each time that a transfer takes place, there is a change. The name of the unique quality which is transferred in many forms to cause natural change is ENERGY.

The capacity to cause natural change is called ENERGY.

One way to classify energy is according to its form. Any kind of change that involves force is called mechanical energy so work is a form of mechanical energy. Other forms of energy are electrical energy, chemical energy, wave energy (energy of light and of sound), atomic energy, and heat energy.

How do we measure energy? A convenient way to measure energy is to measure the work it can do. The SI measurement unit for energy in any of its forms is the joule.

Exercise 16.1

16-1 Energy has been defined as the capacity to do work. Explain.

16-2 Match each term at the left to one at the right. Each term can be used only once.

a. sound energy
b. nuclear energy
c. heat energy
d. mechanical energy
e. chemical energy
f. light energy
g. electrical energy

(1) rusting of iron
(2) high power transmission lines
(3) oven
(4) drum booms
(5) kitchen blender
(6) atom bomb
(7) sunshine

Section 16.2 ENERGY IS CONSERVED

It may look as if energy can just disappear. For example, suppose you do work to start a ball bouncing. The bouncing ball now has energy of motion, but, after a while, it stops bouncing. What happened to the energy? It seems to have disappeared. However, when carefully examined, it is found that the mechanical energy was changed into heat energy because of the friction of the bouncing ball.

In fact, whenever scientists look into examples of energy that seem to have disappeared, they find that it is never really gone. Energy can be changed from one form to another, but none of it is ever destroyed. If it seems to disappear in one form, it shows up in another form.

In 1847, Hermann von Helmholtz published a mathematical paper which helped to establish this idea as a universal rule of nature. It is called the Law of Conservation of Energy, and it states that energy is conserved. Here, *conserved* means that the same total is present at the beginning and end of a process. This means that energy can be changed from one form to another, but it cannot be destroyed. Even if the energy is split up in many directions in many different forms, they all add up to what was initially transferred.

THE LAW OF CONSERVATION OF ENERGY:
ENERGY IS NEITHER CREATED
NOR DESTROYED

Energy is intangible. It does not occupy any space, nor can you weigh it. As an example, consider light, a form of energy. You cannot pick up a glob of light in your hands and toss it to someone, nor can you send a packet of energy through the mail.

At the beginning of the twentieth century, Albert Einstein theorized that matter is another form of energy. Later, it was shown that matter and energy can indeed be changed into each other. Nuclear energy (atomic energy) is the name given to the energy which can be obtained by conversion of nuclear matter to energy.

The most dramatic example of the Law of Conservation of Energy in modern times occurred when the first atom bomb was exploded in 1945. When that happened, a small quantity of mass was transformed into an equivalent quantity of energy. The energy appeared as a violent, tremendous blast.

Total energy used = total energy produced

The energy that can neither be created nor destroyed includes all the energy (including the mass) of the universe. As far as we know, nowhere in our universe has energy ever been created. It was there when the universe started and it is all still there. It has not changed since time began.

Exercise 16.2

16-3 A scientific law is a mathematical description of a natural relationship which agrees with all the facts. Why is Conservation of Energy called a law rather than a theory?

16-4 Explain how each of the following demonstrates the Law of Conservation of Energy.
- a. A space rocket re-enters the atmosphere. It starts to slow down due to friction. The nose cone of the rocket becomes very hot and begins to glow.
- b. Electrical energy is used to light a fluorescent bulb.
- c. A metal strip is bent back and forth until it breaks. At the line of break, it is hot.

16-5 How did the theories of Albert Einstein change the way we understand the Law of Conservation of Energy?

Activity 16.2 TRANSFORMATION OF ENERGY

Purpose: to observe an energy transformation
Materials: plastic jar with cap, about 100-200 mL, sand to fill 2/3 of jar
Procedure: Fill about 2/3 of the jar with sand and cover tightly. Shake the jar of sand vigorously up and down for one minute.

Questions

Q. 1 What change(s) did you observe?
Q. 2 How is your answer to Q 1 related to the concept that energy has many forms?
Q. 3 What does the Law of Conservation of Energy tell you about what you observed?

Section 16.3 KINETIC AND POTENTIAL ENERGY

16.3 A DEFINITION OF KINETIC AND POTENTIAL ENERGY

Because energy appears in so many forms and is so central to science, it acts as a unifying core for science. A search for energy which seems to have disappeared has helped solve scientific puzzles innumerable times. Another type of classification which is helpful in dealing with energy divides it into two fundamental types, kinetic (kinn-ETT-ik) and potential (puh-TENN-shull), depending on whether it involves motion.

***KINETIC ENERGY** is energy of motion (kinetic means moving).*

***POTENTIAL ENERGY** is stored energy due to position.*

16.3 B KINETIC ENERGY

Anything moving has energy simply because it has motion. A moving ball has kinetic energy even though it is not doing any work. It has energy because it is capable of doing work; it can strike something and exert a force on it.

Many of the forms of energy listed before can be classed as kinetic energy. The kinetic energy of moving electrons is a form of electrical energy. Light and sound are both forms of kinetic energy.

Kinetic energy is directly proportional to the massof an object and is directly related to the speed of the moving object.

16.3 C POTENTIAL ENERGY

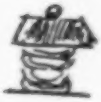
Potential energy is stored energy due to position. For example, suppose you lift a baseball onto a shelf. The baseball doesn't look any different than it did before, but it is different. It has gained energy. If the shelf is removed, the ball falls and can do work by striking something beneath it. It has energy simply due to its position above the ground. What gave it the energy that it used to do work? You did it by lifting it up in our Earth's gravitational field.

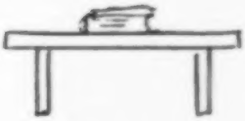
The potential energy due to its height is stored while the baseball is up on the shelf. The higher up it is, the more potential energy it has. When it falls, it falls faster and faster each second; the potential energy is being transformed into kinetic energy.

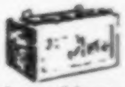
Objects can have potential energy due to their positions in gravitational, electrical or magnetic fields. A wound-up spring has potential energy because of its coiled position. A rubberband gains potential energy as it is stretched.

Note that it takes energy to place an object into a gravitational, electrical, or magnetic field or to coil or stretch it. This is the energy that is stored in the object as potential energy.

POTENTIAL ENERGY

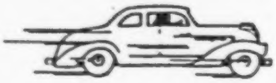






charged battery

KINETIC ENERGY



Exercise 16.3

16-6 A book is lifted from the floor and placed on a bookshelf.

a. What is the name for the energy to lift the book and put it on the shelf?
b. Does the book sitting on the floor have energy?
c. Does the book sitting on the shelf have energy?

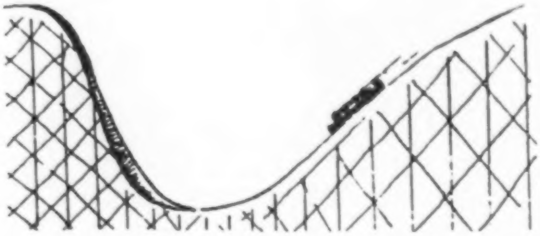
16-7 a. How can something that is moving have energy even though no work is being done?
b. How can something that is standing still have energy even though no change is taking place?

16-8 Two identical racing cars are moving down a racetrack. One is moving at 120 miles per hour and the other at 140 miles per hour.

a. Which has more kinetic energy?
b. Which has more potential energy?

16-9 Two race cars are moving down the track at the same speed. One has twice as much mass as the other. Which has more kinetic energy?

Optional: Section 16.4 THE ROLLER COASTER: EXCHANGE OF KINETIC AND POTENTIAL ENERGY



Potential energy can be transformed into kinetic energy, and kinetic energy can be transformed into potential energy. Picture a car at the top of a road that dips between two hills. To get the car up there, gravity has to be overcome by doing work to push the car up the hill. The car gains potential energy from its position higher up.

If the car is not braked, it will roll back down the hill, losing potential energy. The potential energy can't just disappear; it has to be transformed into something else. Where is it?

If you answered that the potential energy was changed into kinetic energy, you were right. As the car rolls down, it speeds up.

As the car rolls down, it loses potential energy, and as it speed ups, it gains kinetic energy. When it gets to the bottom of the hill, it has lost all of the potential energy it had gained by being raised to the top. All of its potential energy has been transformed into kinetic energy. At the bottom, its speed and its kinetic energy are at a maximum and its potential energy is zero.

At the bottom of the hill, the car would keep going on at high speed in a straight line if the other hill weren't in its way. The second hill pushes the car upward (Newton's Laws), changing its direction. As a result, the car goes back up the hill again. Let's assume that there is no friction involved in all of this. As the car goes up the hill, it slows down due to the force of gravity.

**Q. 1 Does the slowing down of the car mean that it is losing energy?

As the car slows down, it loses kinetic energy. At the same time, it gains potential energy because it is moving higher and higher up the hill. The kinetic energy that seems to be disappearing is instead being transformed into potential energy. The total energy of the car without friction remains the same -- the sum of the kinetic and potential energies.

Were it not for the frictional energy losses (changes to heat energy) that are always present in our real world, the car would keep rolling up and down between the two hills forever.

Roller coasters operate on the same principles. A moving track carries the car up to the highest point. After that, it rolls along on its own exchanging kinetic and potential energy, down and up and around. If there were no friction, the car would move around the roller coaster forever. As it is, friction slows the car so that it loses the kinetic energy needed to go up as high as before. To keep it rolling, the tracks are set lower and lower. After the car has slowed down almost all the way, it is braked to a safe halt.

A pendulum also works the same way. The string controls the direction of motion of the pendulum instead of the track. The pendulum bob moves back and forth just the way that the car goes up and back between the two hills.

Exercise 16.4

16-10 On a ski holiday, Ronald goes to the top of Killer Ski Slope and then swoops all the way to the bottom safely.

a. When is Ronald's gravitational potential energy at its maximum?

b. What kind of energy was transformed into the potential energy?

c. What happened to the potential energy partway down the hill and to what was it transformed?

d. Discuss the energy changes in the skiing that Ronald did downhill.

Answer to Q

Q. 1 If the process is frictionless, there is no way for the car to lose energy. Otherwise, it would violate the Law of Conservation of Energy.

Section 16.5 ENERGY CONSUMPTION: BLESSING AND DANGER

Humans require energy in the form of food just to survive. To live comfortably in a civilized setting is very expensive in terms of energy. Thanks to the blessings of machines, medical advances, and chemicals, people can expect to live until old age and to have many conveniences and comforts available. To make all this possible, vast quantities of chemical energy, mechanical energy, heat energy, and electrical energy are consumed every day.

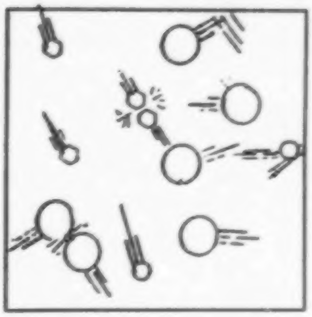
A problem that humanity faces is how to ensure that there will be sufficient supplies of energy to enable life to continue comfortably in the future. Nuclear energy, solar (sun) energy, wind energy, and energy from flowing water are possible future sources of energy.

In primitive times, there were not many people on the earth and so there was very little pollution produced by their use of energy. Now, the world is very populous and largely civilized. The tremendous consumption of fuel is generating dangerous pollution with dust, acid, and harmful chemicals in the air, ground, and waters. Each generation must ensure by careful study and supervision of the earth's resources and physical condition that it maintains the good health of the Earth. Else, the Earth may someday be damaged beyond repair.

Exercise 16.5

16-11 Modern energy consumption has both good and bad in it. What is good? What is bad?

Section 16.6 KINETIC MOLECULAR THEORY: PARTICLES IN MOTION



So far, the kinetic energies of entire objects have been discussed. The kinetic energies of the particles (atoms, molecules, and ions) that make up the objects involve some different and interesting aspects. The ***KINETIC MOLECULAR THEORY** is about moving particles of matter.* It is one of the most firmly accepted theories of science.

According to the kinetic molecular theory, the particles that make up matter (molecules, atoms, and ions) are always moving. Moreover, they are moving in all directions, colliding all the time, and bouncing off again in another direction.

PARTICLES MOVE RANDOMLY IN STRAIGHT LINES ALL THE TIME.

***RANDOM** motion means motion in any direction.* Each particle (molecule, atom, or ion) moves all the time in a straight line interrupted by frequent collisions which keep changing its direction. Hence, it has random motion.

Exercise 16.6

16-12 A crystal of table salt is on a sheet of paper.
- a. Are the particles that make up the crystal moving?
- b. Are the crystals moving?

16-13 How can a particle move in a straight line and have chaotic zigzag motion?

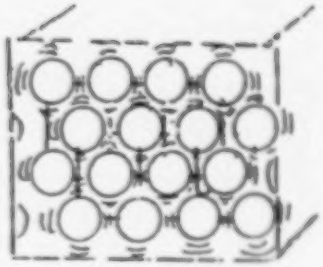
Section 16.7 KINETIC MOLECULAR THEORY: THE THREE STATES OF MATTER

Section 3.9 pictured the three states of matter in terms of the particles that make them up, but the model was a static (motionless) one. The kinetic molecular theory extends this model as follows.

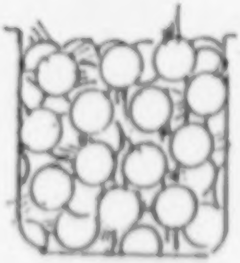
Gases: Gas molecules zoom all over the place while colliding with other molecules. Hence, gas molecules can move as far apart from each other as the container permits and completely fill the container.

Liquids: In liquids, the particles move closely around each other at high speeds with collisions all the time. A glass of water on the kitchen counter may look as if the water is standing absolutely still but its molecules are in constant motion slithering past each other.

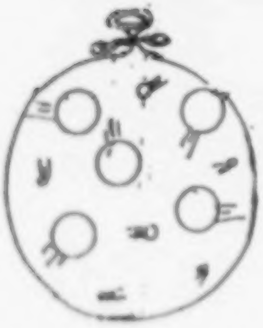
Solids: In solids, the molecules can't exchange places or move past each other but they can jiggle back and forth randomly around their positions.



Solid
Particles are in a regular arrangement, very close, and jiggling in place.



Liquid
Particles are in an irregular arrangement, very close, moving past each other, often bouncing off each other



Gas
Particles are in an irregular arrangement, far apart, zooming around, frequently colliding.

Exercise 16.7

16-14 What is the difference between the positions of the moving particles in a gas, liquid, and solid?

Section 16.8 HEAT ENERGY

Throughout human history, heat has always been important. The cold that the last glaciers brought required all the ingenuity of our savage ancestors to survive. Primitive peoples worshipped fire. Today, we easily bring heat into our homes with chemical fuels or electrical energy and remove heat on a hot summer day with air conditioners. We worry about global warming.

In ancient times, people believed that heat was matter. The alchemists listed heat as an element along with some twenty other elements such as iron and gold. Heat is not matter; it is a form of energy.

**Q. 1 Can you pick up a little heat all by itself and toss it over to someone else?

Heat is the total energy of motion (potential and kinetic) of all the individual particles that make up a substance. It is the internal energy of motion of matter.

The internal kinetic part of heat energy is different from the energy of motion of a moving object. If a bowling ball is flung onto an alley, all the particles of the ball are hurtling together down the alley. This is the energy of motion, not heat energy. At the same time that the ball goes down the alley, all the separate particles are moving randomly in various directions within the ball; this is heat energy.

Another name for heat energy is **thermal energy**. Since heat is a form of energy, the SI unit for it is the joule.

Exercise 16.8

16-15 Name three ways in which heat is used in your home.

16-16 Suppose that an iron bar at room temperature is massed on a laboratory balance. Then, it is heated to red-hot and massed on the balance again (with special care to protect the balance). Is the mass of the hot bar higher, lower, or unchanged from that of the cold iron?

16-17 How does the kinetic energy of heat differ from the kinetic energy of a moving object?

16-18 What is meant by saying that heat is intangible?

16-19 Which needs more heat to become 1°C warmer, a gram of aluminum or a kilogram of aluminum?

Answers to Q
Q. 1 no

Activity 16.3 WHAT IS HOT? WHAT IS COLD?

Purpose: to classify words used to describe hot or cold
Materials: writing tools and paper
Procedure:

1. Think of words to describe "hot" and "cold". On a sheet of paper, draw a line down the center. On the left side, write as many words as you can for "hot". On the right side, write as many words as you can for "cold". Try to list at least ten words on each side.
2. Find two words on your list that are exact opposites. Draw a straight line connecting each such pair of words.
3. Find two words on your list that are exactly the same. Draw a curved line connecting each such pair of words.
4. How many words on your list are connected to temperature? Put a check next to each one.

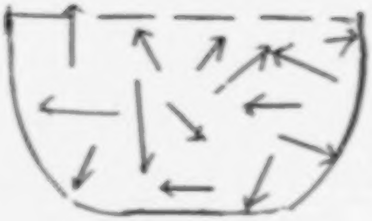
Section 16.9 KINETIC MOLECULAR THEORY; TEMPERATURE

We know that there is a connection between temperature and heat. You can warm something up by adding heat and cool it by removing heat. Yet, heat and temperature are not the same. For example, you can heat up a cupful of water to boiling. The same quantity of heat added to a tub of water will barely change its temperature.

If heat is a form of energy, what is temperature? In everyday terms, ***TEMPERATURE*** *is a measure of how hot or cold something is.* What is it scientifically? The kinetic molecular theory provides a very satisfactory answer.

To put it briefly,

FOR ANY GIVEN MATERIAL, THE FASTER THE AVERAGE SPEED OF THE PARTICLES, THE HIGHER IS THE TEMPERATURE



Imagine a bowlful of water. All the particles are moving back and forth randomly, exchanging places, bumping into each other, and travelling in zigzag motions. The speed and direction of each particle is constantly changing. Because the particles of matter are always colliding, some particles speed up to faster than the average while others are slowed to less than the average speed. For each particle, the speed is constantly changing.

According to the kinetic molecular theory, when the temperature is increased in the bowl of water, the particles, on the average, move faster. When the temperature is lowered, the average speed decreases.

Hence, the higher the temperature, the greater the average random kinetic energy. The lower the temperature, the lower the average random kinetic energy. At the same temperature, all matter, regardless of its physical state or identity, has the same average kinetic energy.

TEMPERATURE IS DUE TO THE AVERAGE RANDOM KINETIC ENERGY OF THE PARTICLES OF MATTER.

You can feel the temperature of the air around you because the energy of the random impacts of the molecules affects sensors in your hands. Similarly, when a spoon feels hot to your hand, it is because your skin has detected that the atoms are moving faster than the particles of your skin.

For any given set of particles:

kinetic energy	average particle speed	temperature
increases	faster	higher
decreases	slower	lower

Because temperature depends on the average kinetic energy per particle, the temperature can be the same for 10 g or 10 000 g of a substance. Heat depends on the quantity of material but temperature does not. Recall that heat is the total internal energy of motion; temperature represents the average internal kinetic energy.

Since it has to do with energy, temperature cannot be weighed, gathered into a bundle or separated from matter. Temperatures cannot be measured directly from the kinetic energies of the separate particles. Instead, the *effects* of temperature are used for measurements. The ordinary household thermometer tells temperature based on changes in the volume of a liquid.

Even though we cannot see it, the invisible particles of matter at ordinary temperatures are moving at tremendous speeds. The invisible particles of a substance such as the oxygen molecules in the air are moving at about the speed of a rifle bullet. Each second, an oxygen molecule collides thousands of times with other air molecules.

When it becomes cooler outside, all the particles of the air move less rapidly; they collide less often and with less force.

To briefly summarize the differences between heat and temperature:

Heat	Temperature
Kinetic and potential energies of particles	Kinetic energy of particles
Total of above	Average of above

Activity 16.4 MOTION OF PARTICLES

Purpose: to observe changes due to motion of particles
Materials: medicine dropper, 2 beakers or glasses, one bottle food coloring, paper towel
Procedure:
Step 1: PREPARATION

1. Obtain the materials.
2. Fill one glass with very hot water.
3. Fill the other glass with very cold water.
4. Dip a medicine dropper into the bottle of food coloring and lift some out.
5. Wipe the food coloring from the outside of the dropper with the paper towel.

Step 2:

1. The two glasses of water should show no movement of the water by the time you are ready to begin this step. Hold the medicine dropper so that it is just above the surface of the cold water and release one drop onto the surface. Do not allow the dropper to touch the water surface.
2. Make sure that the outside of the dropper is dry and, in the same way, add a drop of coloring to the hot water.

Conclusion: What conclusions can you draw about the arrangement and motion of the molecules of the cold water? What can you conclude about why the color spreads differently when the temperature is higher?

Exercise 16.9

16-20 Which has a higher temperature, matter with its particles moving at high average speeds or the same matter with particles moving at lower speeds?

16-21 36 g of nitrogen are in one jar and 40 g of nitrogen are in another jar. They are both at the same temperature. Which has the higher average random kinetic energy?

16-22 Which gas has the higher average random kinetic energy, 5 g nitrogen at 20° or 20 g of nitrogen at 15°C.

16-23 How does the movement of air particles on a cold day differ from air on a hot day?

Section 16.10 HEAT FLOW

HEAT ALWAYS FLOWS FROM A WARMER OBJECT (higher temperature) TO A COOLER ONE. A thermometer tells us which way the heat will flow.

When a warmer object meets a cooler one, the faster moving particles in the warmer object slam into the slower moving ones of the cooler object. The slower moving ones are speeded up; the faster moving ones are slowed down. Hence, the cooler object warms up and the warmer one cools down. This continues until they are both at the same temperature.

**Q. 1 A jar of hot soup is placed next to a jar of cold water in an insulated box. The hot soup starts to cool. Where does the heat flow go?

**Q. 2 How long does the heat from the hot soup continue to flow out?

Exercise 16.10

16-24 You hold your friend's cold hand for a minute. Does your friend's hand become colder or warmer? Explain in terms of heat flow and the kinetic molecular theory.

Answers to Q's

Q. 1 It heats up the cold water.

Q. 2 It continues to flow until the soup and water are at the same temperature.

Activity 16.5 RELATIONSHIP BETWEEN TEMPERATURE AND VOLUME

Purpose: to predict how changes in the temperature of a gas affect its volume and to test the prediction experimentally.

Discussion: Suppose that you have a balloon which you have blown up and tied closed. You now have an elastic container full of gas. It is elastic because there are ways that you can make the balloon with the enclosed gas expand or contract.

Based upon what you know about the kinetic molecular theory, you are in a good position to make a prediction about the relationship between the temperature and volume of a gas. Your prediction will cover what happens to the volume of the gas

when the temperature of the gas is increased,

(does the balloon become bigger, smaller, or stay the same), and

what happens to the volume of the gas when its temperature is decreased

(does the balloon become bigger, smaller, or stay the same)?

Since all gases have similar properties, your prediction should apply pretty much to any gas. The gas could be expelled air from your lungs, oxygen, nitrogen, carbon dioxide, or whatever.

Next, devise one or more experiments to test your prediction.

Hypothesis: Make your prediction as discussed above. Add a paragraph to explain how the kinetic molecular theory leads you to this hypothesis.

Procedure: Devise and carry out an experiment to test your hypothesis.

Report Sheet: Write up a report similar in style to the Report Sheets that you have been using all year. Be sure to include your hypothesis with an explanation based on the kinetic molecular theory. Describe the procedure you use. Your description of the procedure should be such that someone who reads it can do the experiment.

Conclusion: State what kind of relationship there is between the temperature and volume of a gas. Explain how you reached this conclusion. Report on how it agrees or disagrees with the kinetic molecular theory. You may need to use drawings in your explanation.

Activity 16.6 RELATIONSHIP BETWEEN PRESSURE AND VOLUME

Purpose: to predict how changes in the volume of a gas affect its pressure and to test the prediction experimentally.

Materials: 2 clear plastic cups, bucket of water

Discussion: The prediction you are asked to make concerns the relationship between the pressure and volume of a gas. Pressure is defined as force per unit of area. In the case of a gas, the force is exerted on the walls of the container that holds the gas. According to the kinetic molecular theory, the particles of the gas bounce against the walls, rebound, collide with each other, bounce off the walls again, and so on. The numerous impacts against the walls of the container and the force of those impacts result in pressure upon it.

Suppose you cause the same gas to occupy a smaller container. What happens to the pressure of the gas now that the container is smaller. Does it increase, decrease, or stay the same?

Hypothesis: Based on the kinetic molecular theory, predict what will happen to the pressure of a gas when the volume of its container is changed. Add a paragraph to explain how your prediction is based on the kinetic molecular theory.

Procedure: To test your hypothesis, try the following.

Step One:

1. Obtain the materials.
2. Take one of the cups, invert it, and push it down into the water until at least half of the inverted cup is submerged. Don't let it tilt. Does it stay down in the water? How do you get it to stay down?
3. Observe the cup as you hold it in the water. Does the cup fill with water? Before going on to Step Two, answer the questions below. Discuss them with your partner before you write down the answers.

Questions

Q 1 What happened to the volume of the enclosed air in the cup when you pushed the cup into the water? How do you know?

Q 2 Were you able to just put the inverted cup into the water or did you have to exert a force on it?

Q 3 If you had to exert a force on the cup of air, what must also be true according to Newton's Third Law?

Q 4 Based on your answer to Q 3, what has happened to the pressure of the air inside the cup?

Q 5 What is the relationship shown in this experiment between the volume and pressure of a gas?

Step Two: Are you sure that there was air in the cup after you pushed it into the water? Something had to be there otherwise the water would have filled the cup. Here's a quick way to show that air was in the cup all the time. To demonstrate this, do the following.

1. Place one of the cups into the bucket of water and tilt it so that it fills up with water. Keep it inverted.
2. Take the other cup and invert it. Lower it into the water without tilting it. Move it until it is under the edge of the other one. Now, allow it to tilt until bubbles escape from it upwards into the other cup.
3. Try to empty the air out of one cup into the other.
4. Complete the Report Sheet.

Conclusion: State what kind of relationship there is between the pressure and volume of a gas, based on your experiment. Explain how you reached this conclusion based on Steps One and Two. Report on how it agrees or disagrees with your initial hypothesis and why. You may need to use drawings in your explanation.

Activity 16.7 RELATIONSHIP BETWEEN TEMPERATURE AND PRESSURE

Purpose: to predict how changes in the temperature of a gas affect its pressure and to test the prediction experimentally.

Hypothesis: Based on Activities 16.5 and 16.6, you have enough information to make predictions on how a change in temperature will affect the pressure of an enclosed gas.

Procedure: To verify the hypothesis, you are asked to consider the pressure in car tires. The pressure can easily be read with a tire gauge, although a little air is lost when the gauge is put on the tire stem. When a car is driven over a distance, there is always friction on the tires. The friction causes the tires to heat up. There you have it. The data that you need are the air pressures before and immediately after driving the car for a distance. The car should be in the shade for the first measurement and not have been used for at least one hour. It should be returned to the same spot for the final measurement. Obtain the needed data from parents who are willing to help. Ask them to check not only the pressures but the fact that the tire does feel warm. The same tire has to be checked before and after. After enough data has been collected, the class can compare them.

Report Sheet Write up a report similar in style to the Report Sheets that you have been using all year but also describe the procedure. Report on precautions taken to keep all variables the same before and after the experiment except for the ones being tested. Report the data.

Conclusion: What kind of relationship there is between the temperature and pressure of a gas? How does the data verify your hypothesis? How does it agree or disagree with the kinetic molecular theory? You may need to use drawings in your explanation.

Section 16.11 ABSOLUTE ZERO

Can ice be cooled below 0°C?

Ice can certainly be cooled below its freezing point and is found well below zero naturally at the earth's poles. Is there a limit to how far below 0°C temperatures can drop?

The answer to this is yes. As temperature decreases, the random motion of the particles decreases. Eventually, there is a bottom temperature at which there is no random movement at all. This is the true zero temperature, the lowest temperature possible in our universe.

SI measures temperature in kelvin units.* The kelvin scales uses the same degrees as on the Celsius scales but starts at the lowest temperature possible in our universe, zero kelvin (0 K). This absolute zero is about -273°C, the temperature at which all random particle motion ceases.**

Exercise 16.11

16-25 What is the lowest temperature in the kelvin scale that can possibly be achieved? Why?

16-26 Which of the following are impossible temperatures?
a. -10°C; b. -10 K; c. -300°C; d. 0°C

Section 16.12 HEAT AND CHANGES OF STATE

16-12 A PHASE CHANGES

When matter changes from one physical state to another, it is called a
CHANGE OF STATE

Another name for state of matter is **PHASE OF MATTER** so a change of state is also a phase change.

The phase changes which can occur are listed below along with the names commonly used for these changes. Matter can change from solid to liquid to gas or the reverse.

Phase Change	Name of Change	Heat
solid to liquid	melting	added
liquid to solid	fusion or freezing	removed
liquid to gas	vaporization or boiling	added
gas to liquid	condensation	removed

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*The kelvin temperature scale differs from the Celsius scale only in that it starts at the true zero temperature, the lowest possible temperature. Notice that the kelvin scale does not use the degree sign, °. For example, zero kelvin is abbreviated as 0 K. Twenty kelvins is 20 K; it equals -253°C.

The quantity of heat energy added to change matter from one phase to another is the same quantity of heat energy that must be removed to reverse the phase change.

**Q. 1 How would you change an ice cube to a liquid? Where might the energy come from?

**Q. 2 How could you remove energy from cold water to freeze it?

There is one phase change which has not yet been discussed. If you have ever seen a light sprinkling of snow disappear from the ground even though the outdoor temperature is below the freezing point of water, you have seen this change. It is the *change from solid to gas without going through the liquid state, called* ***SUBLIMATION*** *(sub-lih-MAY-shun).* It occurs with certain solids such as ice and solid carbon dioxide (dry ice) under the right conditions.

**Q. 3 Is heat energy added or removed during sublimation?

The quantity of heat energy which must be added or removed from a substance to change its phase

(1) depends on the identity of the substance, and
(2) is directly related to how much there is of it (mass).

Exercise 16.12A

16-27 A machine which makes ice cream is responsible for which change of state? Does it add or remove heat energy?

16-28 What is the difference between melting followed by vaporization as compared to sublimation?

16-29 Does heat energy have to be added or removed to
- a. change a liquid to a solid?
- b. lower the temperature of a liquid?
- c. boil a liquid?
- d. condense a gas?
- e. raise the temperature of a gas?
- f. cool a solid?
- g. freeze something?
- h. melt something?

16-30 The heat of fusion of water is 84 kJ/kg.
- a. Define the heat of fusion (hint: note the units).
- b. If 84 kJ of heat energy are added to 1 kg of ice at 0°C, what happens?
- c. How much heat energy must be added to 2 kg water at 0°C to melt it?
- d. If 84 kg of heat energy are removed from 5 kg water at 0°C, what happens?

Answers to Q's

Q. 1 Heat energy has to be supplied to the ice cube (heat flow to the cube). To supply the energy, place it next to something warmer such as warm water, a flame, or an electric heater.

Q. 2 To remove energy from cold water, place it in contact with something colder. Heat flows from the warmer object to the colder one.

Q. 3 Since this is a change of state from gas to solid, heat energy must be added even though it takes place without becoming a liquid first.

16.12 B TEMPERATURE DOES NOT CHANGE DURING PHASE CHANGES

**Q. 1 What is the temperature of an ice cube while it is melting?

**Q. 2 What is the temperature of the melted water with the ice cube in it?

While a change of state takes place, the temperature of the system does not change. The heat added or removed during a change in state is never accompanied by a change in temperature.

While a substance is melting, its temperature does not change. All of the added heat is used just to pull the particles away from each other. The solid and the liquid in it are both at the same temperature.

There is also no change in the temperature of a substance while it boils or condenses. Water boils at 100°C no matter how much there is of it; the boiling water and the vapor boiling out are both at 100°. Pure water freezes at 0°; the ice formed and the water in the ice-water mixture are both at 0°C.

**Q. 3 When you increase the heat under a pot of boiling water with an egg in it, does the egg hard-boil in less time?

A change in the phase of a substance involves rearranging the positions of the moving particles. When a solid changes to a liquid, the particles are now able to change places and to move around and a little away from each other. When a liquid changes to a gas, the particles separate and move completely away from each other. The heat energy is used to change the potential (positional) energies of the particles, not their kinetic energies.

When heat is added to matter without a change of state, it increases the temperature (increases the average kinetic energies of all the particles).

Exercise 16.12 B

16-31 For each of the following, state whether the temperature increases, decreases, or stays the same.

a. Heat is added to a cupful of water at 20°C.
b. A bowl of water is being heated at 100°C.
c. A large block of ice is at 0°C. A little heat is added to it.
d. A cupful of water at 20° is set onto a block of much colder material and allowed to stay there for a while.
e. A block of ice is cooled.
f. Glycerine is being boiled for five minutes.

Answers to Q's

Q. 1 and Q. 2 The temperature of both the water and the ice cube are 0°C.

Q. 3 The egg does not boil any faster since the temperature of the boiling water doesn't change. All that happens is that more of the water boils away.

Chapter 16 Review

Vocabulary

joule
liquid
temperature
kinetic
conserved
solid
atomic energy
random

From the list of words above, pick the one which best fills a blank in the following. Each vocabulary word above may be used only once.

1. particles jiggle in place: ________________
2. energy stored in the nucleus of an atom: ________________
3. energy unit: ________________
4. moving: ________________
5. total energy stays the same: ________________
6. any which way: ________________
7. average random kinetic energy: ________________
8. particles move around each other, touching: ________________

Applications

State whether each of items 1-17 are true or false.

1. The molecules are all moving in a glass of water which is standing still without a ripple.
2. Chemical energy can be converted to electrical energy.
3. Force multiplied by distance equals energy.
4. The quantity of heat inside an object is all kinetic energy.
5. Heat always flows from a cooler object to a warmer one.
6. The quantity of heat in an object can be weighed.
7. More heat has to be added to 100 g of water than to 10 g of water to raise its temperature by 5°C.
8. Matter may be changed to energy.
9. To change a liquid to a gas, heat must be removed from the liquid.
10. To melt a solid, heat must be added.
11. When heat is added to a substance at its boiling point, its temperature increases.
12. All the particles of a liquid at room temperature are moving at the identical speed.
13. Every substance at the same temperature has the same average random kinetic energy.
14. Heat is the average kinetic energy of motion.
15. The boiling point of a substance does not depend on how much there is of the substance.
16. Newton said that matter is a form of energy.
17. One joule of heat energy equals one joule of energy of motion.

For items 18-35, select the best choice.

18. In which of the following is energy not conserved?
    a. a candle burns
    b. light is emitted from an electric bulb
    c. a ball stops bouncing
    d. energy is conserved in all of the above.

19. Electricity is used to turn on a mixer. Electrical energy is
    a. lost.
    b. converted to kinetic energy.
    c. converted to potential energy.
    d. gained.

20. The gravitational potential energy of an object is directly related to
    a. its speed.
    b. its chemical composition.
    c. its position on the map.
    d. its distance above the ground.

21. A car speeding along the ocean beach has
    a. kinetic energy but no potential energy.
    b. potential energy but no kinetic energy.
    c. both kinetic and potential energy.
    d. neither kinetic nor potential energy.

22. While lying on the sands on the beach alongside the ocean, you have
    a. kinetic energy but no potential energy.
    b. potential energy but no kinetic energy.
    c. both kinetic and potential energy.
    d. neither kinetic energy nor potential energy.

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23. At room temperature, the particles that make up the lattice of any solid
a. are motionless
b. jiggle back and forth
c. roam around freely
d. move only by exchanging positions

24. To lower the temperature of a solid
a. heat can be added to it.
b. heat can be removed from it.
c. heat may be either added or removed.

25. The quantity of heat needed to melt a lead bullet is
a. greater than
b. the same as
c. less than
} the heat needed to solidify the bullet after it has melted

26. When an ice cube is forming in water
a. the ice cube is at 0°C and the water is below °0.
b. the ice cube is at 0°C and the water is at °0.
a. the ice cube is at 0°C and the water is above °0.
a. the ice cube is below 0°C and the water is above °0.

27. In order to cause condensation
a. heat must be removed from the material.
b. heat must be added to the material.
c. either of the above is true.
d. neither of the above is true.

28. When the temperature of a gas is increased,
a. the average speed of its particles increases.
b. the average speed of its particles decreases.
c. the mass of the gas changes.

29. Which has the greatest average random kinetic energy?
a. 100 g ice at -10°C
b. 10 g ice at 0°C
c. 5 g water at 15°C
d. All of the above have the same average random kinetic energy.

30. At the temperature of 0 K, the random kinetic energy of a gas is
a. the same as at 273°C.
b. the same as at 0°.
c. zero.

31. The lowest temperature that can possibly be reached in our world is
a. 0° C; b. 0°F; c. 0 K; d. -100°C

32. Which of the following has the highest boiling point?
a. 100 g lead
b. 10 g lead
c. 1 g lead
d. All of the above have the same boiling point.

*33. A pendulum is set to swinging. Which of the following is true at the top of the swing?
 a. potential energy is at a maximum and kinetic energy is zero
 b. potential energy is zero and kinetic energy is at a maximum
 c. potential and kinetic energies are both at their maximum
 d. potential and kinetic energies are both zero

*34. When friction is operating, the sum of the potential and kinetic energies of a moving object
 a. decreases
 b. remains constant
 c. increases
 d. increases and then decreases

The following items require a short answer.

35. Coal and oil are fossil fuels. When fossil fuels are all used up, what other energy sources do you know of that can be used to replace them?

*36. A ball is thrown straight up. As it moves upward, it goes more and more slowly till it stops and then starts to fall down again. Describe the changes in the potential and kinetic energies of the ball at the bottom of the throw and the top.

*37. A large steel box is sealed and thrust into a hot electrically-heated oven.

a. Describe what happens to the air inside the heated box in terms of the molecular kinetic theory.

b. Suddenly, there is a tremendous explosion and the parts of the stove and box fly apart in all directions. Fortunately, no one is hurt. What happened?

*38. A hot air balloon ascends into the skies when its density becomes less than that of the surrounding air. How does heating the air in the balloon cause it to rise? Explain in terms of the molecular kinetic theory.

GLOSSARY

ACCELERATION: change in velocity per time

AIR RESISTANCE: upward pressure of air against a falling object

ALPHA RAYS: fast-moving helium particles stripped of electrons, He^{2+}, formed during radioactive decay

ARTIFICIAL RADIOACTIVITY: radioactive decay of elements that are not found in nature.

ATOMIC FUSION: when two or more nuclei combine to form a nucleus of higher atomic number

ATOMIC NUMBER: the number of protons in the nucleus of an atom

BALANCED expression: the total number of atoms of each element in a reaction expression is equal on both sides

BETA RAYS: high energy electrons formed during radioactive decay

BINARY COMPOUND: made up of only two elements

BOILING: change of state from liquid to gas

BRITTLE: can't be stretched and breaks on bending

CATALYST: helps a reaction to take place but is not itself used up in the reaction

CAUSE OF ERROR: error built into the activity which is beyond your control

CENTI-: one hundredth (1/100)

CHANGE OF STATE: when matter changes from one physical state to another

CHEMICAL BOND: holds two atoms together

CHEMICAL BONDING: process of forming stable links between atoms

CHEMICAL CHANGE: when the identity of a sample of matter changes

CHEMICAL TREATMENT: exposure of a material to various other substances and to different temperatures and pressures to encourage reactions

CHEMISTRY: the study of the identity of matter and of the changes matter can undergo

CLASSIFICATION: the process by which bits of information are grouped together according to similarities

COMPOUND: pure matter made up of chemical combination of atoms of different elements

COEFFICIENT: a number which multiplies the formula that directly follows it

COLUMN: see FAMILY

COMPOUND MACHINE: combination of simple machines

COMPOUND MOTION: when motion of an object can be analyzed as made up of motion in two different directions

CONDENSATION: change of state from gas to liquid

CONSTANT: property that does not change under the given conditions

CONSTANT SPEED: same as Uniform Motion

CONSTANT OF PROPORTIONALITY: in an equation with a Per Fraction, the constant that the Per Fraction equals

CONTROL EXPERIMENT: same experiment but without the special condition that was tested

CONTROLLED VARIABLE: variable which is not allowed to change during an experiment

COVALENT BOND: when atoms are held together by a pair of shared electrons

CRITICAL MASS: minimum mass that has to be brought together for a chain reaction to occur by fission

DATA: record of observations

DECI-: one tenth (1/10)

DECOMPOSE: break down into two or more different materials

DECOMPOSITION: a single compound is broken down into two or more different substances

DEGREE: name for one measurement unit of temperature

DENSITY: mass per volume of a sample of matter

DEPENDENT VARIABLE: the variable that changes when the independent one changes

DIATOMIC MOLECULES: made up of two atoms each

DIRECT RELATIONSHIP: when two variables always change at the same time in the same direction

DIRECTLY RELATED: same as Direct Relationship

DOUBLE DISPLACEMENT: two compounds react and exchange elements

DOUBLE REPLACEMENT: see Double Displacement

DUCTILE: can be stretched into thin wires

DUPLET: two and only two electrons around a nucleus

EFFICIENCY of a machine: compares the actual to the ideal work

EFFORT FORCE: force applied to a machine by the user

ELECTRON: fundamental carrier of negative charge

ELECTRON CONFIGURATION: the arrangement of the electrons around the nucleus of an atom OR the number of electrons around the nucleus and their distribution

ELEMENT: matter that cannot be separated into simpler substances by chemical treatment

ENERGY: capacity to cause natural change

ENERGY LEVEL: region in atom of a principal Bohr orbit

ESCAPE VELOCITY: speed of an object needed to completely depart from the Earth's gravitational attractive force

EXPERIMENT: activity in which changes are made to take place and the results observed

EXPRESSION of a reaction: word or formula statement which states the reactants and products of a reaction

FACT: observation confirmed by reliable observers

FACTOR: multiplier

FAMILY in periodic table: vertical column in periodic table in which the elements have similar chemical properties

FISSION: the process whereby a heavy atom is split by impact of another particle into two or more nuclei

FIXED PULLEY: pulley which can rotate but can't be moved to another location

FORCE: push or pull

FORMULA: tells the elements and number of atoms of each present in a molecule or formula unit of a substance

FORMULA UNIT: one of whatever is described by the formula

FREEZING: change of state from liquid to solid

FULCRUM: edge which fits under a board and allows it to pivot

FUNDAMENTAL DIMENSIONS: length, mass, and time

FUSION: same as Freezing (also see Nuclear Fusion)

GAMMA RAYS: extremely high energy form of invisible light

GAS: matter which always completely fills its container

GRAVITY: force of attraction between any two masses

GROUP in periodic table: see FAMILY in periodic table

HALF-LIFE: time it takes for one-half of a sample of radioactive matter to decay

HEAT ENERGY: internal energy of motion of matter

HYPOTHESIS: a guess, based on insufficient information, about the answer to a question

INCLINED PLANE: tilted flat surface

INDEPENDENT VARIABLE: the variable that the scientific experimenter causes to change

INDIRECT RELATIONSHIP: see Inverse Relationship

INERTIA: tendency of matter to stay in place or to keep moving at the same speed

INSOLUBLE: solvent cannot dissolve the smallest visible quantity of solute

INVERSE RELATIONSHIP: when two variables always change at the same time in opposite directions

IONIC BONDS: bonds between positive and negative ions

IONS: particles which have gained or lost electrons

ISOTOPES: atoms of the same element that contain different numbers of neutrons

JOULE: newton-meter

KILO-: one thousand (1000)

KINETIC ENERGY: energy of motion

LAW: description of natural relationship that has been learned from facts

LEVER: board or stick on a fulcrum

LIQUID: matter which takes the shape of the container and fills it from the bottom up

MALLEABLE: can be bent or dented

MASS: the quantity of matter in an object

MASS NUMBER: sum of the numbers of protons and neutrons in an atom

MATTER: something which takes up space and can be pushed or pulled

MEASURE: find how much there is of something

MECHANICAL ADVANTAGE: a ratio which compares the force needed without the use of a machine to that applied by the user to the machine to do the same task

MELTING: change of state from solid to liquid

MILLI-: one thousandth (1/1000)

MODEL: visual or mathematical picture or structure suggested by data

MOLECULE: neutral particle made up of two or more atoms held together by covalent bonding

MOLECULAR FORMULA: formula which shows the identity and number of atoms of each element in one molecule

NATURAL RADIOACTIVITY: radioactive decay of elements that exist in nature.

NEUTRAL: equal quantity of positive and negative charge

NUCLEUS of atom: the core of the atom which contains all of the protons and neutrons

NUCLEAR FUSION: when nuclei combine to form a heavier nucleus

NEUTRON: nuclear particle which has no charge

NEUTRAL ATOM: an atom with equal numbers of positive and negative charges

OBSERVATION: information obtained through the use of the senses

ORBIT (Bohr): location in atom where groups of electrons can be found

ORDERING: arranging bits of information in a sequence

PER: for each or for every

PER FRACTION: quantity of one variable per quantity of another variable

PER ONE FRACTION: Per Fraction with a denominator of one measurement unit

PERIOD: horizontal row in periodic table

PHASE OF MATTER: same as State of Matter

PHYSICAL CHANGE: a change in a property of a substance without change in its identity

PLANE: flat surface

POLYATOMIC ION: charged group of covalently bonded atoms which react together as a group

POTENTIAL ENERGY: stored energy due to position

POWER: energy per unit of time

PRESSURE: force per area

PRODUCTS of a chemical reaction: substances which are produced

PROPERTY of matter: characteristic of matter

PROPORTIONAL: when two variables always change at the same time by the same factor OR when two variables, y and x, may be described by the equation, $y = kx$.

PROTON: fundamental particle that carries positive charge

PULLEY: wheel which is turned by a rope or chain that fits around its rim

PURE matter: has the same identity throughout

QUALITATIVE: description of a property where no measurement is taken

QUANTITATIVE: description of a property that requires a measurement

QUANTITY: a number AND its measurement label

RAD: unit of the absorbed dose of radiation

RADIATION: transfer of light through space

RADIOACTIVE DECAY: see Radioactivity

RADIOACTIVITY: any decomposition of the nucleus

RADIOTRACER: molecule used for analysis in which one of the atoms has been replaced by a radioactive atom

RANDOM MOTION: motion in any direction

REACTANTS: substances which react together

RECIPROCAL: inverse (upside-down) of a number or of a quantity or of any fraction

RELATIONSHIP: connection between two variables such that one of them changes whenever the other changes.

REM: unit of radiation based on quantity and type

RESISTANCE, machine: weight lifted by a lever

SCREW: shaft with a spiral around it which acts as an inclined plane

SHELL (Bohr): see ENERGY LEVEL

SIMPLE MACHINE: allows the applied force to be changed by changing the distance and/or the direction over which the force must operate

SINGLE DISPLACEMENT : a reaction in which an element or group replaces an element or group in another compound

SINGLE REPLACEMENT: see Single Displacement

SOLID: matter which retains its shape regardless of the container

SOLUBLE: a visible quantity of substance can dissolve in a given solvent

SOLUBILITY: the maximum quantity of solute that can dissolve in a given quantity of solvent under stated conditions

SPEED: distance covered per unit of time

STANDARD UNIT: an accepted measurement for ONE quantity of a particular property

STATE OF MATTER: gas, liquid, or solid OR physical form in which matter may be found

STATIC FRICTION: force between two surfaces which acts to keep objects from moving when a force is applied to one of the objects

STATIONARY FRICTION: same as Static Friction

STEADY SPEED: same as uniform motion

SUBLIMATION: change of state from solid to gas without going through the liquid phase

SUBSCRIPT in a chemical formula: a number which is placed after an element in the formula slightly below the line OR a number which tells how many atoms there are of the element that it follows in the formula

SUBSTANCE: pure matter OR any element or compound

SUPERSCRIPT of an ion in a chemical formula: a raised number followed by a plus or minus sign which tells the charge on the ion that it follows

SYNTHESIS type of equation: two or more elements combine to form a single compound

TEMPERATURE: how hot or cold something is

TERMINAL VELOCITY: constant velocity reached when the air resistance equals the downward pressure exerted by a falling object

THEORY: an explanation which connects the facts and does not contradict any of them

THERMAL ENERGY: heat energy

UNBALANCED FORCE: force which is not cancelled by an opposing force

UNIFORM MOTION: same speed throughout

VAPORIZATION: particles of liquid enter gaseous state

VARIABLE: property that can vary (change) under the given conditions

VOLUME: the space occupied or enclosed by something

VELOCITY: speed plus direction

WEIGHT: downward force that an object exerts due to gravity

WEDGE: block which tapers to a thin edge

WHEEL AND AXLE: a shaft or pole (axle) passing through the middle of a wheel which rotate together

WORK: force multiplied by the distance along which it operates

YIELD in a chemical reaction: produce (verb) or products (noun)

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